SilTools

Developer's Guide

SILMA®
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Using this Manual

Manual Conventions

The following sections describe conventions which have been used in this manual to denote specific concepts.

For the following, **this typeface** is used:

- booleans
- statements
- commands
- variables
- object names
- operators

Example: **mk_rctcurve (pts: darray of pnt3dr; n: integer);** is an operator.

The SIL Prompt

The SIL prompt is shown by: SIL>. When you see the prompt, it means that the code following it can be entered exactly as shown. If the line following the SIL> prompt line is in `this font`, this is the result of the command. Example:

```
SIL>  monthly_salary(team1_leader);
3541.666748
```

In this example, you would enter **monthly_salary(team1_leader);** at the SIL> prompt. After you press <RETURN>, `3541.666748` would be displayed in the shell window.

SIL Syntax

Sections showing syntax of more than one line have a box around them. The code sometimes contains variables indicated by <> symbols.

```
function f(x:A;<a1>:<type1> ....):<result-type>;
  var …
  begin
  …
  end;
```

SIL Code Examples

The examples are printed in gray boxes. They include explanatory text and code. The code may be entered as shown.

Example 1.1

Assignment statements:

```
x := sin(y); x := x + 1, table[6] := 0; employee.salary := x;
```

Procedure calls:

```
writeln('hello', '...', 'world');

deposit(account, 50.00);
```

Rules

Rules are shown with a dark gray title bar and a box around the rule.

Rule 1.1

```
<sequence> := begin <statement>; …; <statement> end;
```

Windows

Windows that are part of the display are indicated in *Italics*. Examples: *Quick Pick Window* and *Graphics Window*.

Filenames

`This typeface` is used for filenames. Example: **`default.sil`** is a file.

Keys

Keyboard keys are indicated by the "<>" symbols enclosing the key in capital letters in THIS TYPEFACE. Example: <RETURN> is a key.

The Top Bar

Pulldown menus from the top bar are indicated with bold letters in **This Typeface**. Example: **File** is a pulldown menu.

Panels

Panels are indicated with This Typeface. Example: Collision Detection is the title of the panel that is displayed when you choose *Collision Detection…* from the **Utilities** pulldown menu.

Pulldown Selections and Commands

Selections from the pulldown menus, commands and command buttons are indicated with *Italics in this Typeface*. Examples: *Install…* is a selection from the **Layout** menu, *Apply* is a command.

Toggle Choices

Toggle choices are shown with a ◆ symbol in front of the label. Example: ◆ Checks is a toggle choice.

Switches

Switches are shown with a ❑ symbol in front of the label. Example: ❑ Show Reference Frame.

Fields and Messages

The label and the information in the field are in this typeface. Example: Edge Length displays 1.0 in its field.

Messages, such as instructions and error messages that pop up or are displayed in the panels, are quoted using this typeface. Example: Pick any edge of an object.

Notation

This manual uses simplified grammatical rules (which resemble BNF) to describe syntactic forms. This section describes these rules completely.

These rules use the following form:

<A> ::= exp

where **<A>** is a non-terminal symbol and **exp** is a string of terminal and non-terminal symbols. Interpret the above rule to mean that all occurrences of the non-terminal symbol **<A>** can be replaced by the string **exp**. The goal of a rule such as that described above is to derive syntactically valid strings of non-terminal symbols by repeatedly applying all available rules to a given string until all non-terminal symbols have been replaced.

Five conventions are associated with the rules used in this manual. These conventions provide readers with a means of denoting specific types of symbols and of writing rules in an abbreviated fashion.

1. Rules with the same left-hand side:

   <A> ::= exp1
   <A> ::= exp2
   <A> ::= exp3

   can be rewritten in a single line as

   <A> ::= exp1 | exp2 | exp3

2. Rules with the same right-hand side:

   <A1> ::= exp
   <A2> ::= exp
   <A3> ::= exp

   can be rewritten in a single line as

   <A1>, <A2>, <A3> ::= exp

3. Rules in which one right-hand side is a substring of another:

   <A> ::= ac | abc

   can be rewritten as a single rule:

   <A> ::= a[b]c

   Here **[b]** indicates that the string **b** is optional.

4. Recursive forms can be written with rules such as

   <A> ::= e | e<A>

   or

   <A> ::= e…e

   Here, **e…e** means that **A** can be replaced by a string of one or more **e**'s.

5. A non-terminal symbol is any character string enclosed by angle brackets (<>):

   <parameter list>
   <function application>
   <etc>

All other character strings are terminals.

We can describe all numerals with the following set of rules:

<numeral> ::= [-]<non-zero digit>[<digit> … <digit>] | 0

where

<non-zero digit> ::= 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

<digit> ::= 0 | <non-zero digit>

The numeral -204 can then be derived as follows:

<numeral>
-<non-zero digit><digit><digit>
-2<digit><digit>
-20<digit>
-20<non-zero digit>
-204

Chapter 1

Introduction to the SIL Language

Although the SilTools menus provide most of the commands you need, you can also create your own commands by writing programs in a language called SIL. Using the SIL language, you can develop your own SilTools applications which take advantage of the capabilities that SIL offers. SilTools, in fact, is a SIL application. This manual explains how to program in the SIL language. To use this manual to write your own programs requires some previous programming experience.

SIL is a powerful general-purpose programming language that lies at the heart of SilTools and supports advanced programming methods such as object-oriented programming, concurrent programming, and meta-programming.

This chapter provides an overview of the SIL language, including a simplified model of SIL's runtime environment and the storage model.

SIL Language Overview

The layers of SIL implementation are arranged in the following fashion:

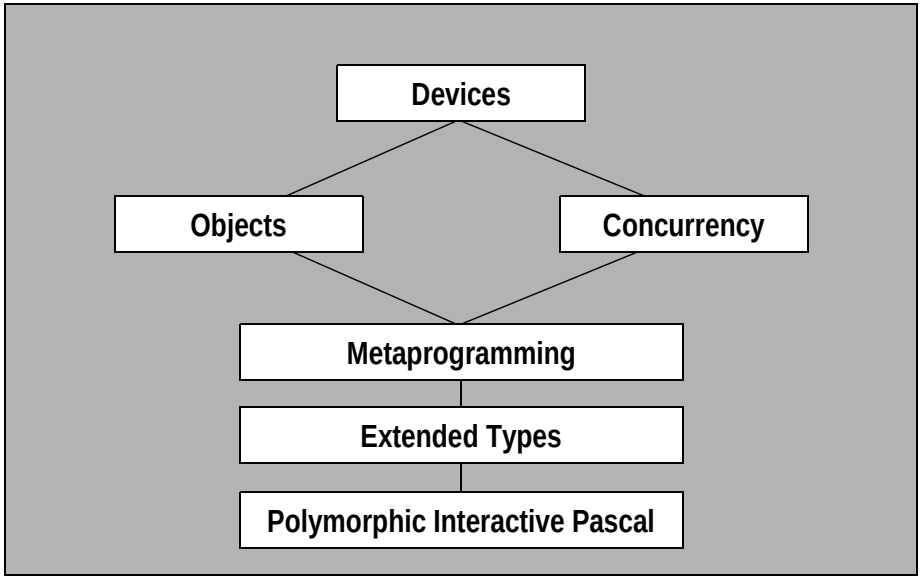


Figure 1-1 The SIL language

SIL Compared to Pascal

SIL and Pascal share many syntactic features. Programmers familiar with Pascal, but new to SIL, can get started by treating SIL as an interactive implementation of Pascal. SIL syntax is a superset of Pascal syntax, and all of the control structures have their usual Pascal meanings—basic data types such as reals, integers, booleans, and records have standard behavior. The difference between the two languages emerges when examining pointer types—SIL maintains pointer structures in a Lisp or SmallTalk-like heap, so that pointer management is different from (and simpler than) Pascal.

Still another feature which distinguishes SIL from Pascal is its polymorphism. SIL is polymorphic in the sense that the same symbol may be used to denote functions of differing input types. For example, the function **double** may be defined both for reals and points, without conflict. This is known as **static polymorphism** (SIL supports other kinds as well). Because the decision of which function variant to use is made at compile time, no performance slowdown occurs.

The SIL Programming Environment

The SIL programming environment, like that of Lisp or SmallTalk, is interactive. Any legal expression can be typed or cut and pasted into the SIL> prompt, including new functions, type definitions, or global assignments. Typing or pasting in expressions results in these new entities being added to the current programming state. In Text Mode, the mouse buttons have different functions (such as cutting and pasting text), which are defined by the operating system.

Uncompiled SIL code is executed by a fast pseudo-code based interpreter. It is possible to compile SIL code, also; to do this, the code is translated first into C and then to binary using the host machine's C compiler. The performance of compiled SIL code is similar to that of corresponding code written directly in C (or Pascal). Interpreted and compiled code may be freely mixed—compiled functions may be replaced at will by modified interpreted variants, allowing fast bug fixing and testing.

SIL uses a generation-scavenging garbage collection algorithm. Even for very large applications, garbage collects are fast (less than one second) and infrequent enough that you will not be able to detect them, as long as you are working on standard UNIX workstation hardware (such as Sun SPARCstations). See “Storage Model” on page 1-23.

Entering SIL Commands

To access the SIL language, you must have a product running. The “Starting SilTools” section in Chapter 2 of the *SilTools User’s Manual* explains how to start a product.

The *SIL Window* can be used to enter SIL language commands while retaining access to the menus and panels. The *SIL Window* is displayed under the *Graphics Window*.

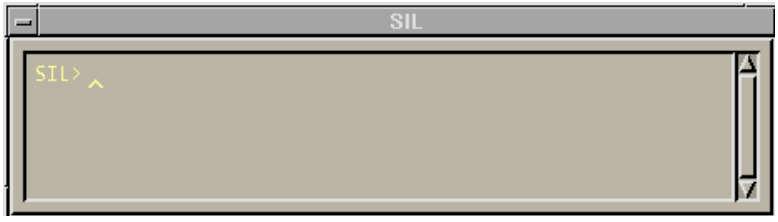


Figure 1-2 The *SIL Window*

You can also change to Text Mode to enter SIL language commands. In Text Mode, you have full editing capability and direct access to the operating system.

Change to Text Mode by selecting *Exit Menus* from the **File** pulldown menu. The menus are disabled and the SIL> prompt is displayed in the shell window that you used to start SilTools.

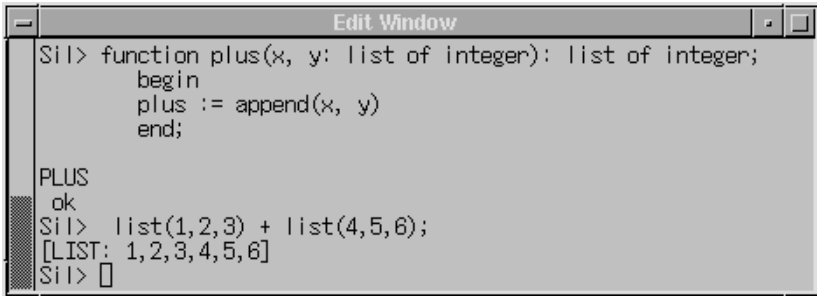


Figure 1-3 Shell window example

Enter **menus();** at the SIL> prompt to restore access to the menus. If the system has become disabled, enter **r();** at the Error> prompt to reset the system.

Extended Types

The SIL type system uses the Pascal typing structure as a starting point and expands on it. First, SIL provides types which are dynamically allocated, and automatically collected from a heap. These types include dynamic lists, arrays, strings, trees, and a special type, **lispob**s (SIL data objects), which is shortened to **ob**. All SIL data are of type **ob**. SIL permits C-style casting; in particular, any SIL expression can be cast to **ob** and back, which allows typed and untyped styles of programming to be freely mixed.

SIL also includes **metatypes**: types which range across language entities rather than across the usual sorts of data. The most important metatype is **ntype**. All types are **ntype**. All SIL data tagged by type is type **universal**. As with **ob**, any SIL expression can be cast to **universal** and back.

The **apply** operator provides runtime or late-binding polymorphism. If some or all of the expressions **e1.. en** are of type **universal**, then **apply("f,e1 .. en)** will search at runtime for a variant of **f** whose input types match the types of **e1 .. en**.

NOTE	Chapter 9, “Advanced Data Types” provides detailed information about the above concepts.

The Object System

The definition of a class in SIL is very similar to a Pascal (or SIL) record definition:

```
type <new-class> = class
   superclass:<class1>;
   superclass:<class2>;

   ...
   <instance-var-1>:<type1>
   <instance-var-2>:<type2>

   ...
   end;;
```

Rather than introducing a special syntax for passing messages, SIL uses ordinary function-application syntax. For example, if **x** is an object, and you want to send it the message **f** with additional arguments **a1 .. an**, you would enter **f(x,a1 .. an)**. Also, to define a method **f** for a class **A**, you would use ordinary function-definition syntax:

```
function f(x:A;<a1>:<type1> ....):<result-type>
   var ...
   begin
   ...
   end;
```

In SIL, as in any object-oriented language, an object usually belongs to several classes—if it belongs to a class **A**, it will also belong to each of the superclasses of **A**, and their superclasses, and so forth. Internally, an object is represented in SIL by a linked list of "views", and one view exists for each class to which the object belongs. A **view** is a record structure containing the values of instance variables for its class, and a few words of object-system overhead. A SIL object can be visualized as a property list, with one property for each class to which the object belongs.

SIL provides direct and flexible access to the views of an object. The function **views(x:A)** returns the view list of any object of any class **A**. It is possible to edit view lists by adding or removing members. View lists admit "object mixins", rather than just "class mixins". For example, to endow an object with both color and weight attributes, simply splice color and weight views onto that object—it is not necessary to define a class which mixes color and weight in advance.

SIL provides both early-binding (compile-time) and late-binding (runtime) mechanisms for method selection. For example, let **B** be a subclass of **A**, and suppose that **f** is a method for **A** but not **B**, and that **e** is an expression of type **B**. In the expression **f(e)**, **e** will inherit the method f from **A**. This inheritance, or method selection, occurs at compile time, so that no runtime overhead is induced (this is like ordinary method selection in C++).

On the other hand, in the following expression,

```
apply("g,e);
```

the views of the object **e** will be searched at runtime until one to which **g** applies is found (this will occur if **e** is of **universal** type and its runtime value is an object, also). This is known as "late binding", which is the scheme used in SmallTalk and Objective C. SIL also provides the equivalent of the virtual function facility in C++.

NOTE Chapter 5, "Classes" provides detailed information about the above concepts.

Concurrency

SIL supports concurrent execution of multiple tasks within one "state" or data space. The SIL implementation provides its own scheduler. Procedures intended for concurrent execution are indicated by using the keyword **task** rather than the keywords **function** or **procedure**. Tasks may include any code which would be legal in procedure or function, and may include primitives for synchronization.

To introduce new threads of computation, use the **start** operator. If **f** is a task, then

start("f,<arg1> … <argn>)

is an expression which will cause the execution of **f** on the given arguments to start as a separate concurrent thread. The **start** expression evaluates to an object of type activation (corresponding to, for example, the process class in SmallTalk, or the thread type in the BSD UNIX lightweight process facility). The activation is a handle to the ongoing computation of **f**. SIL provides various synchronization primitives, all of which rest on two basic primitives: the **semaphore**, and the **delay**. A delay is a suspension for a given amount of time. In this case, time is measured by the "real world clock", or by an internal simulated clock, depending on the application.

NOTE Chapter 10, "Concurrency" provides detailed information about the above concepts.

The SIL Runtime Model

This section contains the following topics:

- *Environments*
- *Values*
- *Expressions*
  - Terms
  - Statements
  - Definitions

SIL is an interpreted language*. This means that an expression is read from a file or the keyboard, and is passed to the SIL interpreter which then computes the value of the expression. The computed value is passed to a printer which writes it to a file or the screen, and the cycle repeats. This sequence in SIL is illustrated below:

```
repeat
   write('SIL> ');       {the prompt prompts}
   exp := read_and_parse(); {the reader reads}
   val := value_of(exp); {the interpreter evaluates}
   writeln(val)          {the printer prints}
until false
```

To compute the value of an expression, the interpreter must be able to look up the values associated with any symbolic names that might occur in the expression. For example, to evaluate the expression

2 * sin(x + pi)

the interpreter must look up the values associated with the names **sin**, **x**, and **pi**. These associations, called bindings, are stored in symbol tables called environments that reside in the SIL virtual memory space.

Figure 1-4 shows a representation of the relationships between the components of the SIL runtime model.

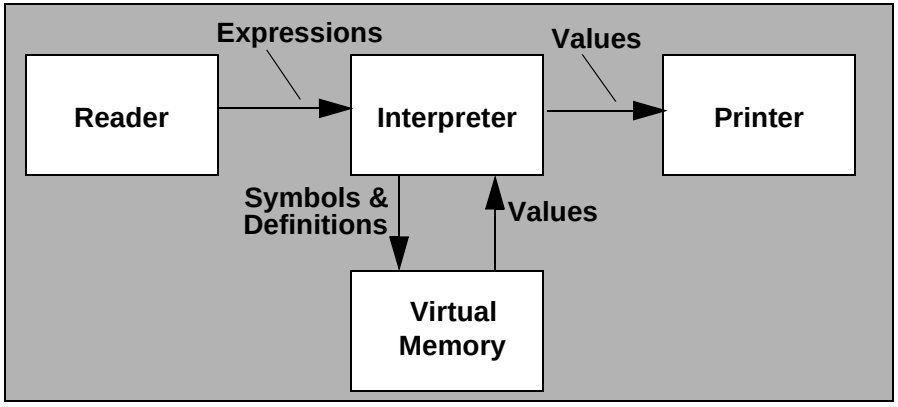


Figure 1-4 The SIL runtime model

* Compilation is also possible (see "Loading SIL Code" on page 11-5).

Environments

Environments are either permanent or temporary. The permanent environment is called the **global** environment. The global environment contains bindings for

- All type names
- Function/procedure names
- Global variables

Local environments contain bindings for

- The parameters of a function/procedure
- The local variables of a function/procedure

Local environments may be considered temporary extensions of the global environment which are created when a function/procedure is called, and destroyed when the function/procedure terminates.

Some expressions modify an environment when they are evaluated by the interpreter. For example, definitions create new bindings in the global environment while assignment statements change the value associated with a symbol in an existing binding.

Example 1.2

Entering the statement

```
x == 2;
```

defines x as a global variable with type integer and value 2. If x had a previous type and value, then this is replaced. The assignment statement to define x is:

```
x := 2;
```

which can be entered directly or can appear inside of a SIL program, assumes that x already has some associated integer value. In this case the old value is replaced by 2.

Values

Values, or data objects, are the scalars and data structures such as numbers, strings, records, and arrays that inhabit the computer's memory and represent abstract entities in the problem domain. The generic term used in SIL to describe all of these objects is **lispob** (which was derived from **LISP OB**ject).

Lispobs may be classified into data types, or, to put it the other way around, a data type can be viewed as a collection of similar **lispob**s. Knowing the data type of a **lispob** is important. For example, this information is used to compute the amount of memory space required to store the **lispob** or to detect inconsistencies in a SIL program.

SIL data types fall into one of three broad categories:

- System-defined types:
  integer, real, boolean, string, …
- Constructed types:
  list types, array types, function types, …
- User-defined types:
  record types, classes, …

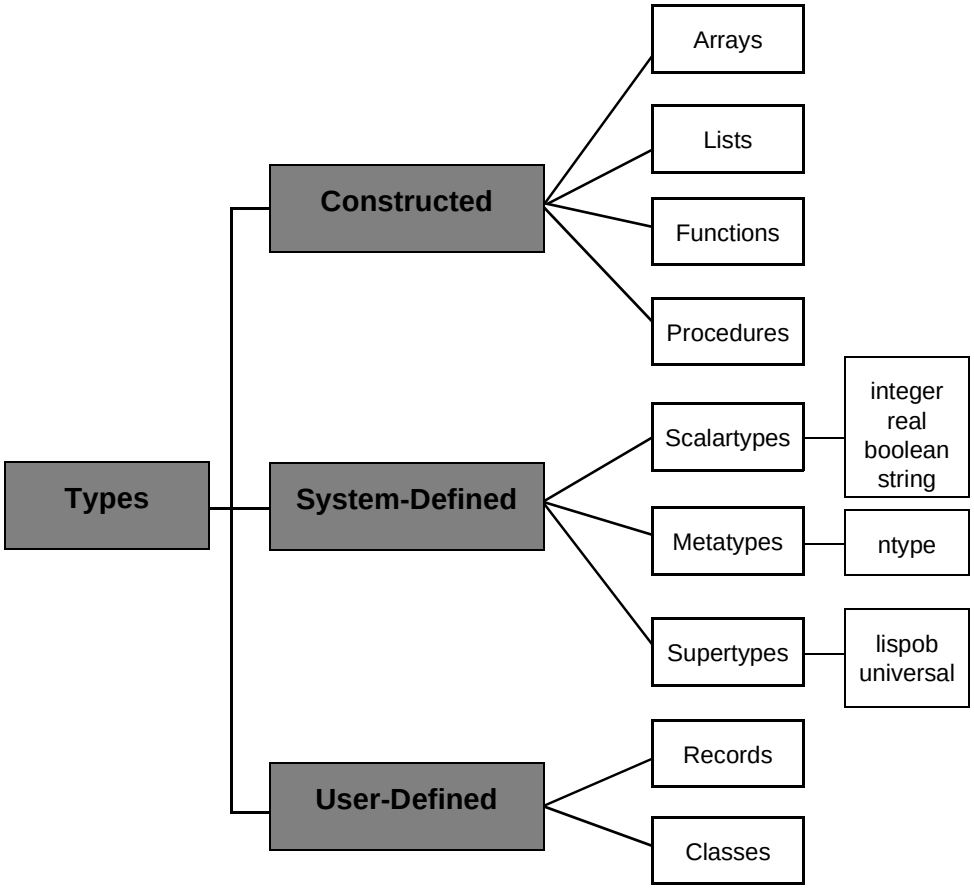


Figure 1-5 Data type classifications

NOTE Chapter 4, “Data Types”, Chapter 5, “Classes”, Chapter 9, “Advanced Data Types” and “Procedures and Functions” on page 2-2 explain the data types in detail.

Expressions

NOTE	This section describes features in SIL which are identical to Pascal, so you may want to skim, or even skip, this section if you know Pascal.

There are three types of SIL expressions: **terms**, **statements**, and **definitions**. This is expressed as Rule 1.2.

Rule 1.2
<expression> ::= <term> | <statement> | <definition>

Terms

There are three types of terms in SIL: **constants**, **variables**, and **function applications**. This is expressed as Rule 1.3.

Rule 1.3
<term> ::= <constant> | <variable> | <function application>

Terms represent values (**lispob**s), although some function applications will also modify an environment as a side effect. The general form of a function application is

<operator>([<term>, … , <term>])

where **<operator>** is the name of a function. The terms appearing inside of the parentheses are referred to variously as the inputs, arguments, operands, or actual parameters. Notice that operands can also be function applications.

Example 1.3	
Constants:	**2, -1.1, pi, "a_symbol, 'a string', nil, true, false**
Variables:	**x, room_temperature, part35**
Applications:	**sin(pi), max(2, x), mod(trunc(sin(x)), 50)**

In addition to the general form of a function application, there are some special forms. Most notable is the case of **infix operators**, which use the form

<term> <operator> <term>

Other examples include special syntax for accessing fields of records and components of arrays, as illustrated in Example 1.4.

Example 1.4

infix operators:	**x + y, x / y, x and y, x > y, x = y**
unary operators:	**-x, not x**
array components:	**table[x]**
field selectors:	**employee.salary, employee.spouse.salary**
mixed:	**table[employee_id].salary**

In fact, all of these forms can be expressed in the general prefix form above. For example, you could rewrite

employee.salary

as

salary(employee)

The term

x + 5

can be rewritten as

plus(x, 5)

and so on.

Evaluating a term containing multiple special operators can be ambiguous. For example, the term

5 - 3 + 2

might evaluate to 0 or 4 depending on which operation is performed first. Similarly, the term

not true or true

might evaluate to **true** or **false** depending on which operation is performed first. Of course, you can dictate the order of evaluation by inserting parentheses at appropriate places in terms. In the absence of parentheses, the interpreter uses precedence rules similar to those used by Pascal to decide the order of evaluation.

For example,

unary operations, **-** and **not**, are always performed first

and

***, /*, **and** are performed before **+, -**, and **or**

Statements

Generally, a statement alters an environment. Statements can be grouped into **atomic** statements and **compound** statements:

Rule 1.4
<statement> ::= <atomic statement> | <compound statement>

Atomic statements are assignment statements and procedure applications. The form of an assignment statement is

<variable> := <term>

The form of a procedure application (also known as a procedure call) is the same as that of a function application:

<operator>([<term>, … , <term>])

where <**operator>** names a procedure instead of a function.

Assignment statement form varies. For instance, the left-hand side of the **:=** symbol can be a term that references a record field or an array component.

Example 1.5

Assignment statements:

```
x := sin(y), x := x + 1, table[6] := 0; employee.salary := x
```

Procedure calls:

```
writeln('hello', '...', 'world');

deposit(account, 50.00);
```

Compound statements are built up from atomic statements using statement constructors. There are three categories of statement constructors: conditionals and case statements, sequences, and iterations (see Rule 1.5).

Rule 1.5

<compound statement> ::= <conditional> | <case> | <sequence> | <iteration>

Sequences are groups of statements that are combined into a single statement by bracketing them between the key words **begin** and **end**.

Rule 1.6

<sequence> ::= begin <statement>; …; <statement> end

The format of a **conditional** statement is expressed in Rule 1.7.

Rule 1.7

<conditional> ::= if <test> then <action1> [else <action2>]

where **<test>** is a Boolean-valued term and **<action1>** and **<action2>** are arbitrary statements. Note that the **else** clause is optional.

If **<test>** evaluates to true, then **<action1>** is evaluated, otherwise **<action2>** is evaluated.

Example 1.6

If **x** and **y** are real-valued variables, then the following statement assigns the absolute value of **x** to **y**:

```
if x >= 0 then
   y := x
else
   y := -x;
```

A typical programming error occurs when **<action1>** is itself a conditional statement with no **else** clause. For example, consider the statement

```
if test1 then if test2 then writeln('hello') else writeln('bye');
```

If **test1** fails, should **bye** be written or not? The problem is that ambiguity arises when determining whether **else** is part of the outer conditional statement or the inner statement. In this situation, the convention is to group the **else** clause with the outer **if** statement. We can group it with the inner statement by inserting **begin** and **end** statements:

```
if test1 then
   begin
   if test2 then
     writeln('hello')
   else
     writeln('bye')
   end;
```

The **case** construct in SIL uses the following form:

```
case <variable> of
   <value>[,<value>,...,<value>]:<statement>;
   ...
   <value>[,<value>,...,<value>]:<statement>;
   [else: <statement>;]
   end;;
```

Example 1.7

```
case numkids of
 0:writeln('childless');
 1,2,3:writeln('small family');
 4,5,6:writeln('mid-sized family');
 else:writeln('big family');
 end;;
```

The **else** clause is optional.

There are several types of **iteration** statements: **repeat**, **while**, and **for**. The **repeat** and **while** statements behave similarly. The syntax for these statements is expressed in Rule 1.8.

Rule 1.8

<iteration> ::= <while> | <repeat> | <for>

<repeat> ::= repeat <actions> until <condition>

<while> ::= while <condition> do <action>

<actions> ::= <action>; ...; <action>

where **<action>** is an arbitrary statement and **<condition>** is a Boolean-valued term.

In the **repeat** statement, **<action>** is repeatedly evaluated until **<condition>** becomes true. Since **<condition>** is evaluated after each evaluation of **<action>**, **<action>** will be evaluated at least once, even if **<condition>** is initially true. On the other hand, the **while** statement evaluates **<action>** until **<condition>** becomes false. In this case **<condition>** is evaluated before each evaluation of **<action>**; so, if **<condition>** is initially false, then **<action>** will never be evaluated.

Example 1.8

A **repeat** statement can be used to check the validity of a user input:

```
repeat
   writeln('do you want to continue? (y/n)');
    readln(response);
    valid := (response = 'y') or (response = 'n')
 until valid
```

An example of **while**:

```
while i >= 0 do
     begin
     writeln(square root of ', i, ' = ', sqrt(i));
      i := i - 1
      end
```

The **for** statement has two possibilities:

- Iteration by incrementing or decrementing an integer valued loop control variable
- Iteration through a list:

Rule 1.9

<for> ::=
for <lcv> in <list> [while <condition>] do <statement> |
for <lcv> := <start> [down]to <stop> [while <condition>] do <statement>

where **<list>** is a list-valued term, **<start>** and **<stop>** are integer-valued terms, and **<condition>** is a Boolean-valued term. **<lcv>** (loop control variable) is an arbitrary variable.

In both types of **for** statements, it is not necessary to declare the loop control variable **<lcv>**. The **while <condition>** is used to terminate a loop before **<lcv>** reaches its final value. In the first **for** statement, **<lcv>** successively takes on each value in **<list>** and evaluates **<statement>**. See “Lists” on page 4-3 for examples of this. In the second kind of **for** statement **<lcv>** is initially set to **<first>**, and **<statement**> is evaluated. Thereafter, **<lcv>** is incremented or

decremented depending on which key word (**to** or **downto**) is used. After each increment/decrement, **<statement>** is evaluated. After **<lcv>** reaches the value, **<stop>** (unless the **while** clause is used), control passes to the next statement.

Example 1.9

This statement accumulates the sum of all prime numbers between 100 and 1000.

```
accum==0
for i := 100 to 1000 do
   if prime(i) then
      accum := accum + i;
```

This **for** statement finds the largest prime below max:

```
found==false;
for i := max downto 0 while not found do
   begin
      solution := i;
      found := prime(solution)
   end
```

Definitions

SIL uses five categories of definitions:

Rule 1.10

<definition> ::= <global variable definition>|
<variable declaration>|
<type definition>|
<procedure definition>|
<function definition>

Globals

The syntax for defining a new global variable or re-defining an old global is

<variable> == <term>

This statement assigns the value of **<term>** to **<variable>**, even if **<variable>** was not previously declared or was assigned a value of a different type.

Example 1.10

```
x == 22;
```

assigns the value 22 to the variable **x**.

```
x == 'hello world';
```

changes the value of **x** to the string **hello world**.

Types

To define new data types, use the following syntax:

type <type definition>; ... ; <type definition>;;

where

<type definition> ::= <type name> = <type>

In this case, **<type>** is a term that evaluates to a data type. Notice the extra semicolon at the end of the declaration. This tells the interpreter not to expect more type definitions.

Example 1.11

We can define several types in a single type definition:

```
type
   years = integer;
   dollars = real;
   employee = record
                 age: years;
                 salary: dollars;
                 name: string
              end;
employee_table = darray of employee;;
```

Functions and Procedures

The format of function and procedure definitions follows Pascal syntax (illustrated in Example 1.12). "Procedures and Functions" on page 2-2 defines functions and procedures in detail.

Example 1.12

A procedure definition:

```
procedure display_employee(e: employee);
   begin
   writeln(e.name);
   writeln(' salary = ', e.salary);
   writeln(' age = ', e.age);
   end;
```

A function definition:

```
function payroll(et: employee_table): dollars;
      var {local variables}
      total: real;
      num_employees: integer;
   begin
      num_employees := length(et) - 1;
      total := 0.0;
      for i := 0 to num_employees do
      total := total + (et[i].salary as_type real);
      payroll := total as_type dollars
   end;
```

Variable Declarations

The format of a variable declaration is

var <variable declarations>; … ; <variable declarations>;;

where **<variable declarations>** is a list of variables followed by a type expression:

<variable declarations> ::= <variable list> : <type>

Variable lists are variables separated by commas:

<variable list> ::= <variable>, …, <variable>

In the global environment, be sure to place a double semi-colon at the end of the variable declaration so that the interpreter will not expect more variable declarations.

Technically, a variable declaration is not a definition (in the sense that a definition associates a value with a name). Instead, a variable declaration associates a type with a name. The type information is needed by the interpreter to evaluate other definitions which refer to the name before the value is known (this is known as **forward referencing** and will be discussed in the next section). In the case of simple types, the declaration attempts to compute an initial value of the appropriate type, and assign it to the name. Again, notice the extra semicolon at the end of the declaration.

Example 1.13

Several variables can be declared in a single declaration:

```
var
   x, y, z: integer;
   a, b, c: real;
   i, j, k: darray of integer;;
```

SIL will initialize integers to 0, reals to 0.0, and arrays to length 0 arrays. You should not, however, depend on this—you should always initialize your own variables.

Storage Model

Most types of SIL data are stored in a memory area called the **heap**. Allocation and reclamation of storage in the heap is managed automatically by an algorithm called a **garbage collector**. The design of the heap and its management is similar to that used in modern implementations of Lisp and SmallTalk. The only pieces of data that are not stored in the heap are the values of local variables of type **integer**, **real**, or **record**. This data is kept in another structure called the **stack**. Any SIL data value other than an integer, real, or record is called a **heapval**. Integers, reals, and records are called **stackvals**.

All SIL data, except integers and reals, include a word called the **tag**. The tag indicates the layout of the fields making up the data. Consider the type

```
type rri_lrec= lrecord real1: real; real2: real; int1: integer; end;;
```

with

```
rriv == mk_rri_lrec(2,3,4);
```

Then the datum representing the value **rriv** has the format

```
<tag | 2.0 | 3.0 | 4>
```

When a **stackval** appears as a field of a record or **lrecord**, its own fields are embedded within the record or **lrecord**.

Example 1.14

```
type rri_rec = record real1,real2: real; int1: integer; end;;

type i_rri_rec = lrecord f1: integer; f2: rri_rec; end;;

i_rri_v == mk_i_rri_rec(99,mk_rri_rec(5,6,7));
```

Then the format of **i_rri_v** is

```
<tag | 99 | tag | 5.0 | 6.0 | 7 >
```

When a **heapval** appears as a field of a record or **lrecord**, the **heapval** datum is not embedded in the record, but rather represented by a pointer, as in Example 1.15.

Example 1.15

```
type i_rri_lrec = lrecord f1: integer; f2: rri_lrec; end;;

rriv2 == mk_rri_lrec(11,12,13);

i_rri_v2 == mk_i_rri_lrec(17,rriv2);
```

The format of **i_rri_v2** is

<tag | 17 | [pointer to rriv2]>

Chapter 2

The Basics

This chapter describes some of the basic features of the SIL language, including on-line help, procedures, functions, polymorphism and input/output.

Accessing Help

SIL includes a simple help facility:

help <name>;

The **help** command prints out all of the variants of the given name, their types, and the name of the file in which they were defined. Example 2.2 shows part of the information printed out for the **plus** command in a SilTools state.

Example 2.1

```
SIL> help plus;
type = FUNCTION(INERTIA_MATRIX, INERTIA_MATRIX,
INERTIA_MATRIX) from file:
        ~/cim/builds/nbot_ops37/s/v_inertia.si
        protection: 0
type = FUNCTION(JV,JV,JV) from file:
        ~/cim/builds/nbot_typ26/s/v2mech2.sil
        protection: 0)
type = FUNCTION(JVR,JVR,JVR) from file:
        ~/cim/builds/nbot_typ26/s/v2mech2.sil
        protection: 0)
type = FUNCTION(AV,AV,AV) from file:
        ~/cim/builds/nbot_typ26/s/v6mech.sil
        protection: 0)
type = FUNCTION(GCOORD,GCOORD,GCOORD) from file:
        ~/cim/builds/device8/s/d2gcoord.sil
        protection: 0)
```

The **help** command also prints out type definitions as illustrated in Example 2.2.

Example 2.2

```
SIL> help point;
type POINT = record
     XC:REAL;
     YC:REAL;
     ZC:REAL;
end;;

from file:
~/cim/builds/device8/s/d2gcoord.sil
protection: 0)
```

Procedures and Functions

This section contains the following topics:

- *Defining Procedures and Functions*
- *Local Environments*
- *Nested Definitions*
- *Recursive Functions and Procedures*
- *Closures*

NOTE This section and “Local Environments” on page 2-6 describe features in SIL which are identical to Pascal, so you may want to skim, or even skip, these sections if you know Pascal.

Defining Procedures and Functions

SIL can be used to define several types of programs. The most common programs are procedures and functions, but SIL also supports tasks, processes, and closures.

> **NOTE** Tasks, processes, and closures will be discussed in later chapters.

The primary difference between a procedure and a function is that a function returns a value, whereas a procedure operates purely by side effect. The syntax for defining procedures and functions is

```
procedure <operator>([<formal parameters>]);
   [var <local variables>]
   <procedure body>;

function <operator>([<formal parameters>]): <type>;
   [var <local variables>]
   <function body>;
```

The optional formal parameters and local variable declarations in the following code are sequences of variable declarations:

```
<local variables>::=
   <variable declarations>; …; <variable declarations>;

<formal parameters> ::=
   <variable declarations>; …; <variable declarations>;
```

The procedure body is an arbitrary **begin**/**end** statement:

<procedure body> ::= begin <statement>; …; <statement> end

A function body is also a **begin**/**end** statement, but requires the presence of a return statement which has the form

<operator> := <term>;

This causes the function to return the value of **<term>** when the function completes execution.

Unlike global variable declarations, local variable declarations do not require an extra semicolon. Examples 2.3 and 2.4 illustrate the use of simple functions and procedures.

Example 2.3

The following are examples of some basic math functions:

```
function square(x: real): real;
        begin
        square := x * x
        end;

function average(x, y: real): real;
        begin
        average := (x + y)/2
        end;

function absolute_value(x: real): real;
        begin
        if x >= 0   then absolute_value := x
          else absolute_value := -x
        end;
```

Example 2.4

Here are some simple procedures for manipulating a global variable called **count**. Unlike the functions in Example 2.3, which compute the value of some mathematical function at a certain input, the procedures below have no return values. Instead they modify count or write messages to the screen:

```
count == 0;

procedure inc_count();
   begin
   count := count + 1
   end;
```

continued on next page

Example 2.4 (continued)

```
procedure dec_count();
   begin
   count := count - 1
   end;

procedure clr_count();
   begin
   count := 0
    end;

procedure show_count();
   begin
   writeln('count = ', count)
   end;

procedure dispatch(cmmd: string);
   begin
      case cmmd of
           'inc' : inc_count();
           'dec' : dec_count();
           'clr' : clr_count();
           'show': show_count();
           else : error('unrecognized command: ', cmmd)
   end
end;
```

Note the use of the error procedure in Example 2.4. The error procedure prints its arguments and returns control to the top-level control loop instead of the function/procedure that called **dispatch**. This is useful because an error in **dispatch** probably means that the function/procedure calling dispatch will also have an error, as will its caller, its caller's caller, etc., up to the top-level control loop.

Local Environments

When a function/procedure is called, the body of the function/procedure is evaluated by the interpreter in a local environment which contains the bindings of the formal parameters to the actual parameters. For example, the local environment created by the call **average(2, 3)** is

symbol	value
x	2
y	3

The interpreter then executes the body relative to this environment:

```
begin
average := (x + y)/2
end;
```

When the interpreter encounters a name which is not bound in the local environment, such as **count** in the body of the procedure **inc_count**, it attempts to look up the value in the global environment. Variables occurring in function/procedure bodies that are not bound in the local environment are called **free variables**.

In addition to parameter bindings, the local environment contains bindings of local variables.

Example 2.5

The procedure application **foo(1,2,3)**, where **foo** is defined by

```
procedure foo(x, y, z: integer);
  var
  a, b, c: integer;
  e: darray of integer;
  begin
  …
  end;
```

continued on next page

Example 2.5 (continued)

sets up the local environment.

symbol	value
x	1
y	2
z	3
a	0
b	0
c	0
e	undefined

Note that **a**, **b**, and **c** are initially assigned 0 values. Generally, when the type of a local variable is simple, the **var** declaration will attempt to determine initial values for them. For more complex types, like records and arrays, the locals are left uninitialized.

Several points should be made here. First, the bindings in a local symbol table are accessible inside of the function/procedure body only. Second, the local environment is destroyed when the interpreter finishes evaluating the body of the function/procedure. When the function/procedure is called again, a new local environment is created.

Nested Definitions

SIL does not permit nested definitions. The only exception to this rule is in the case of variable declarations which can occur inside of procedure/function definitions. This is a significant departure from Pascal which allows type and function/procedure definitions to be nested inside of other function/procedure definitions.

Because SIL does not permit nested definitions, all user-level support function/procedures are defined in the global environment and can be called from the top-level control loop just like their user-level client.

Recursive Functions and Procedures

A **recursive function** (or procedure) is a function which calls itself. Recursive functions can cut through complex programming problems by repeatedly dividing a problem into smaller versions of itself.

Because a recursive function calls itself, the system must know something about the function before the function is defined. This can be accomplished by using what is known as a **forward reference**.

Example 2.6

The standard example of a recursive function is the factorial function which returns the product of all positive integers less than or equal to its argument:

```
{forward reference ...}
var fact: function(integer, integer);;

function fact(n: integer): integer;
    begin
    if n < 0
    then error('input to fact must be non-negative')
    else if n = 0
          then fact := 1 {by convention ...}
          else fact := n * fact(n - 1)
    end;
```

A function type, and therefore variable declaration, has the form

function(<output type>, <input type 1>, ..., <input type n>)

Example 2.7 is a traditional example of a recursive function.

Example 2.7

Euclid's method for computing greatest common divisors:

```
{forward reference ...}
var gcd: function(integer,integer,integer);;

function gcd(x, y: integer): integer;
   begin
   if y = 0    then gcd := x
    else gcd := gcd(y, mod(x,y))
   end;
```

NOTE **mod(x, y) =** the remainder of x/y

When **gcd(15, 12)** is called, this local environment is created:

symbol	value
x	15
y	12

But before the interpreter finishes evaluating the body of this call, and before the local environment is discarded, the call **gcd(12, 3)** is made. This call sets up the following local environment:

symbol	value
x	12
y	3

Before this environment is discarded, the call **gcd(3, 0)** is made and this local environment is created:

symbol	value
x	3
y	0

At this point, we have three distinct local environments created by three distinct calls to the same function.

Closures

Closures are entities in SIL which allow functions to be manipulated as data to be passed to functions, inserted in data structures, etc.

```
function shorter(x,y:string):boolean;
      begin
      shorter := length(x) < length(y);
      end;

shorterc == mk_closure("shorter,function(boolean,string,string));
```

The **shorterc** variable's value is the function **shorter**. Its type is

closure(boolean,string,string)

The **least** function is used as follows:

```
function least(x:list of string;y:closure
                  boolean(string,string)):string;
      var rs:string;
      begin
      if null(x) then error('attempt to apply least to an empty list of
                        strings');
      r := car(x);
      for i in cdr(x) do if y(i,rs) then rs := i;
      least := rs;
 end;
```

least finds the least member of **x** according to the ordering given by **y**:

Example 2.8

```
SIL>  least(list('ab','abcd','e','hello'),shorterc);
e
```

Note that

least(list('ab','abcd','e','hello'),shorter);

would not work. **shorter** is a function, not a data value. Besides, if there were more than one variant of **shorter**, you could not easily determine which version is meant.

Polymorphism

General Information

Consider the following SIL code:

```
function twice(x:integer): integer;
   begin
   twice := x + x;
   end;

function twice(x:string): string;
   begin
   twice := x * x;
   end;
```

In Pascal, these two definitions could not coexist, but they can in SIL because of a feature called **polymorphism**. A polymorphic typing system permits one name, such as **`twice`**, to name several objects at the same time as long as the objects have distinct types, and as long as a selection of which object is meant by the name can be made based on the context in which the name appears.

We call objects having the same name **variants** of the name.

When SIL encounters a name applied to a list of arguments, as in

```
twice('hello!');
```

it looks through the function variants of **twice** to find one whose input types match the types of the arguments. In this case, the second version of twice above is selected. A name can have a *data variant* as well as function variants. For example:

```
twice == 'twice';
```

can be added without disturbing the meanings of **twice** as a string or integer function. Only one such data variant is allowed.

Polymorphism Tricks

You can define your own variants of system-defined functions. This introduces some interesting possibilities. For example, the parser parses infix operators to prefix operators. By defining custom variants of these prefix operators, you can take advantage of the infix syntax (see Example 2.9).

Example 2.9

The parser parses infix operators like + and * to plus and times. Defining your own polymorphic variants of these enables you to call them using the infix operators:

```
function plus(x, y: list of integer): list of integer;
   begin
   plus := append(x, y)
   end;

SIL>  list(1,2,3) + list(4,5,6);
[LIST: 1,2,3,4,5,6]
```

The printer in the read/eval/print loop of the SIL control loop is called **tprint**. Defining your own variant of **tprint** causes your printer to be invoked each time SIL prints one of your objects (see Example 2.10).

Example 2.10

```
type point = record
   xc,yc,zc:real;
   end;;

procedure tprint(x:point);
   begin
   write('[xc:',xc(x),',yc:',yc(x),',zc:',zc(x),']');
   end;
```

and now:

```
SIL>  xx == mk_point(1,2,3);

SIL>  xx;
[xc:1.000000,yc:2.000000,zc:3.000000]
```

Input/Output

This section contains the following topics:

- *Reading from the Keyboard*
- *Writing to the Screen*
- *Reading and Writing to a File*
- *EOF*

Presenting **SIL I/O** capabilities consists mainly of listing conventions which, because of their simplicity, need no explanation. For this reason, this section contains a series of annotated examples. These examples will serve to demonstrate how to use the I/O conventions, and in what context.

Reading from the Keyboard

Example 2.11

Assume that the following declarations are made:

```
var a:integer; b:string;;
```

The **read** command instructs the interpreter to assign the next value it reads to the variable argument of the read procedure (=> indicates input by the user in absence of prompt):

```
SIL>  read(a);
=> 37
SIL>  a;
37
```

More specifically, **read(x)** causes the next token in the input stream to be read in. The type of **x** must be string, integer, real, id, or **lispob**. If the token can be interpreted as a data item of the kind indicated by the type of **x**, then **x** will be assigned this value; otherwise, an error will occur. Any token can be interpreted as a string or **lispob**. The obvious

restrictions apply to integers and reals. IDs must follow the SIL rules for IDs (alphabetic character followed by a sequence of non-delimiters). Reading a token as a **lispob** and a string may yield different results.

Example 2.12

```
var aa :string;;
SIL>  read(aa);
 =>123
```

results in **aa** being assigned the string 123.

```
SIL>  aa == nil;
SIL>  read(aa);
 =>  123
```

results in **aa** being assigned the integer 123 cast as a **lispob**. (see “lispobs” on page 9-4 for more information).

Finally, we note that a quoted string as in

```
'hello there'
```

is read as a single string-valued token.

The **readln** command reads one token from the input, and then discards the rest of the line (if any) on which the token appears.

In addition to the **read** and **readln** procedures, the following functions are available:

- **read_char()** reads just one character, and returns its ASCII code.
- **read_token()** reads one token, and returns it as a **lispob**.
- **read_line()** reads an entire line, and returns it as a string, independent of what may appear in the line.

Example 2.13 shows examples of **read** and **readln**.

Example 2.13

```
SIL>  a == 23;
TRUE
SIL>  b == "b;
TRUE
SIL>  begin readln(a);readln(b);
      end;
23 45
abc
 ok
SIL>  a;
23
SIL>  b;
ABC
SIL>  var a:string;;
TRUE
SIL>  read(a);
=> 'hello goodbye'
ok
SIL>  a;
hello goodbye
```

More than one item can be read from a line:

```
SIL>  a==23;
TRUE
SIL>  b==2.3;
TRUE
SIL>  begin read(a);read(b);end;
=> 1 2
ok
SIL>  a;
1
SIL>  b;
2.00000
```

Writing to the Screen

Example 2.14

Assume that we assign values to the following variables:

```
a := 9;
b := 'the value of a is ';
```

The **writeln** statement causes the interpreter to print the values of its arguments on the screen followed by a carriage return and a line feed:

```
SIL> writeln(a);
9
OK
```

The **write** statement suppresses the carriage return/line feed:

```
SIL> begin write(b); writeln(a) end;
the value of a is 9
OK
```

Reading and Writing to a File

Example 2.15

ASCII files are organized into lines. One line is specified as the current line. To perform file I/O, follow these steps.

Step 1: Declare a variable of type **text**:

```
var data : text;;
```

text is the data type of an ASCII file.

Step 2: The statement

```
data := mk_file('/people/me/my_data.txt');
```

associates the pathname **`/people/me/my_data.txt`** to the text variable data.

continued on next page

Example 2.15 (continued)

Step 3: The procedure:

open(data,'output')

allows us to write to the file with pathname **`/people/me/my_data.txt`**.

The procedure:

open(data, 'input')

allows us to read from the file with pathname **`/people/me/my_data.txt`**.

A text variable cannot be simultaneously open for input and output.

WARNING The arguments to **open** are case sensitive.

Step 4: Writing to a file. Assume that data is open for output. The procedure

writeln(data,a);

writes the value of **a** to the current line of the file assigned to data, and advances the current line of data to the next line.

write(data,a);

writes the value of **a** to the next line without changing the current line.

Step 5: Reading from a file. Assume that data is open for input. The procedure

readln(data,a);

assigns the next token to the variable **a**, and advances the current line to the next line. The procedure:

read(data,a);

assigns the next token to **a**, but does not advance current line.

Step 6: After any I/O session the file must be closed. The procedure:

close(data)

closes data and resets its current line to the first line.

EOF

Example 2.16

Assume that data is declared, created, and opened for output as in Example 2.15. The statement

```
SIL> for i := 1 to 20 do writeln(data, i * i);
```

writes the squares of the first 20 integers to data. Assume that data is subsequently closed and re-opened for input.

```
SIL> while not eof(data) do begin readln(data,a);
     writeln(a) end;
 1
 4
 9
 16
 25
 36
 49
 64
 81
 100
 121
 144
 169
 196
 225
 256
 289
 324
 361
 400
```

Additional operations on files are

read_char(<text>)
read_token(<text>)
read_line(<text>)

Symbols

This section contains explanations and examples of the following topics:

- *Identifiers*
- *Useful Symbol Operations*
  - Intern
  - Concatenation
  - i_tsetq
  - id2string

A **symbol** is a name. Constants, variables, type names, and function/procedure names are examples of symbols.

SIL features symbols that not only *name* data objects (**lispob**s), but are data objects themselves. In this way, a symbol can be passed to a function/procedure as a parameter, returned from a function as a value, or can be named by another symbol (which might be a variable or a constant).

Example 2.17

pi names the real 3.141598

integer names the data type integer

Assume the following definitions:

```
x == 0;

procedure foo();
   begin
      writeln('hello world')
   end;
```

Then **x** names the integer 0 and **foo** names the procedure defined above.

Identifiers

The SIL data type of all symbols is called **id** (which is short for **ID**entifier). Of course, SIL expressions must distinguish between use and mention of an **id**. To make this distinction, precede all mentions of an **id** with double quotes (**"**).

Example 2.18

Assume the symbol x names the lispob 0:

```
x == 0;
```

Next, the symbol y names the symbol x:

```
y == "x;
```

Notice that in this expression we are using the symbol y, but mentioning the symbol x; thus we precede x by double quotes.

We can keep going and let the symbol z name the symbol y, and so on:

```
z == "y;
```

The following terms all have value 0:

```
x, value_of(y), value_of(value_of(z))
```

Useful Symbol Operations

The following section contains descriptions and examples of commonly-used symbol operations.

Intern

To promote a string to a symbol, use the following construction:

```
intern(<string>)
```

This constructs and returns a symbol with print name **<string>**.

Concatenation

To concatenate two (or more) symbols and return a new symbol:

<symbol1> * <symbol2> * …

Example 2.19

```
SIL> "cat * "fish;
CATFISH
```

i_tsetq

To assign a **lispob <value>** of type **<type>** to **<symbol>** from inside of a program, use

i_tsetq(<symbol>, <value>, <type>)

id2string

To get the print name of an **id**, use

id2string(<symbol>)

Example 2.20

```
SIL> id2string("CATFISH)
CATFISH
```

Chapter 3

SilTools Geometry

This chapter explains the geometric terms used in SilTools and contains instructions for manipulating geometry with SIL commands instead of the menus. These instructions are provided for programmers who need a fairly detailed guide for performing geometric manipulations.

Understanding SilTools Geometry

Spatial geometry or simply, geometry* is the means of describing how objects are situated in the region of three-dimensional space being simulated.

With SilTools, geometric descriptions are used to construct and locate simulated objects. SilTools uses those same geometric descriptions to perform kinematic transformations on the simulated objects for moving them around the simulated space.

Geometric Terms

The language used in this manual and when speaking about SilTools entities contains terms like **coordinate system**, **frame**, **pose**, and **reference system**. The following items explain the distinctions between these terms.

- All shapes have a pose.
- Frame shapes are a special kind of shape (which also possess a pose).
- The current reference frame is some shape's pose.
- Frame shapes are physical objects in the simulated world, and can usually be picked with the mouse like any other shape.
- Poses can be displayed, but are ephemeral—they cannot be selected.

* Chapter 2 of *Introduction to Robotics* by John J. Craig (Addison-Wesley, 1989) provides detailed information on the concepts in this chapter.

Every point on an object has a fixed location relative to its pose. When you manipulate objects, you only need to be concerned with their poses.

NOTE "Poses" on page 3-16 describes poses.

Shape

To simulate objects in a three-dimensional space, SilTools manipulates a data structure in which all simulated objects are represented by a type called **shape**.

To handle multiple shapes, SilTools arranges all shapes in the simulated world in a tree structure. The root of this tree is a special shape which lacks any associated geometry and is called **`world`**.

Frame

SilTools provides a special kind of shape called a **frame** which is used primarily for teaching desired positions of objects (e.g., via points in a path along which another shape will move). The geometry of a frame shape is shown on the right-hand side of Figure 3-1—one axis looks like an X, one like a Y, and the Z axis looks like a pointer. Because a frame is also a kind of shape, it has a pose which lies coincidently with the frame's geometry.

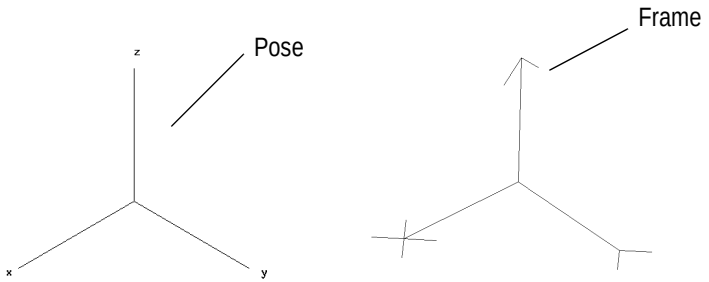


Figure 3-1 Coordinate frames

Geometric Units

To specify positions and orientations, you need a way of specifying lengths and rotations.

The default unit for length in SilTools is centimeters. All other units of length are based on this default and are easily defined.

Example 3.1

To use the meter (100 centimeters) as your default unit. This unit is defined with a SIL **const** declaration:

```
const meter:=100;
```

To express a length in meters rather than in centimeters, the length is simply multiplied by the constant. For instance, a length of 5 meters would be written as

```
5 * meters
```

Some units of length are already pre-defined as global constants in SilTools. They are inch (2.54 centimeters), foot (30.48 centimeters), mm (0.1 centimeters), and mil (0.00254 centimeters).

The default unit for rotation is degrees. The size of a rotation is the number of degrees in the swept angle. **Positive (+) rotations** are taken to be counter-clockwise looking down the positive axis of rotation toward the plane of rotation. **Negative rotations** are clockwise. A pre-defined constant rad (180/pi degrees) is provided for working in radians.

The following equation returns a value of 180:

```
pi * rad;
```

Position

A **position** is a property of points that describes a point's location relative to some known reference frame. The position of the point is at X, Y, Z in Cartesian coordinates. In SilTools, the units of position are specified by centimeters by default (but can be changed easily to the units of your choice).

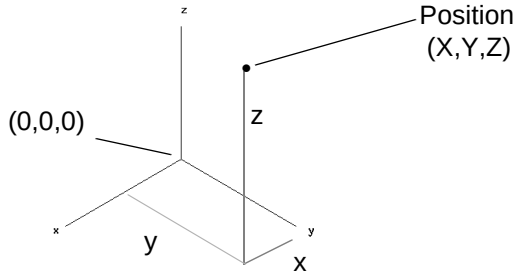


Figure 3-2 Position

For example, every point on an object has a position relative to the frame of that object. Every frame has a position relative to some other frame determined by the location of its origin (a point) in that frame. A convenient way to depict position is with a vector pointing from the reference frame's origin to the positioned point.

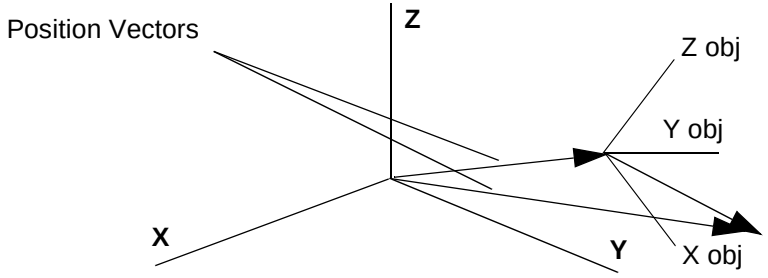


Figure 3-3 Position vectors

A point's position is specified by its reference frame coordinates. SilTools provides three useful coordinate descriptions: Cartesian, cylindrical and spherical.

Cartesian Description

The most common is the Cartesian description where the point's coordinates are its X, Y, and Z distances from the reference frame's origin.

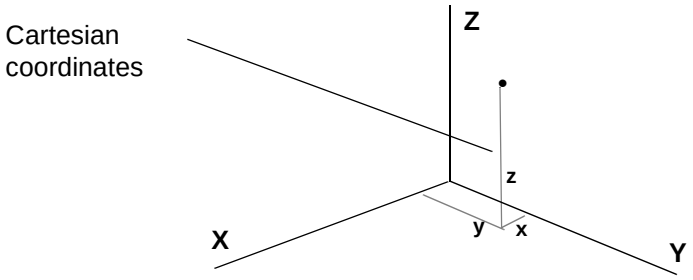


Figure 3-4 Cartesian coordinates

Use the type **crt** to construct a Cartesian position using this command and syntax:

mk_crt(<xc>,<yc>,<zc>);

or

mk_point(<xc>,<yc>,<zc>);

Cylindrical Description

Another type of position is the cylindrical description in which the point's coordinates are its angular distance from the X axis measured counter-clockwise in the XY plane of the reference frame, its radius normal to the Z axis, and its height along the Z axis.

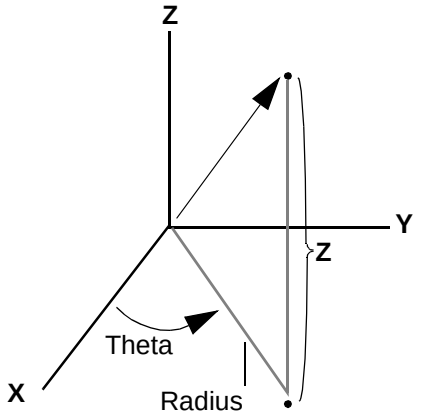


Figure 3-5 Cylindrical coordinates

Use the type **cyl** to construct a cylindrical position using this command and syntax:

mk_cyl(<rad>,<theta>,<zc>);

Spherical Description

The final description is spherical, in which the point's coordinates are its radius from the origin of the reference frame, its angular distance from the X axis (longitude), and its angular distance from the XY plane (latitude).

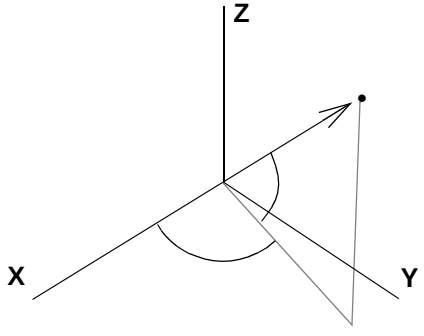


Figure 3-6 Spherical coordinates

Use the type **sph** to construct a spherical position using this command and syntax:

```
mk_sph(<rad>,<lng>,<lat>);
```

Orientation

Orientation is a property of objects that describes how the object's frame is aligned relative to a reference frame. Orientation is specified in terms of rotations of the object's frame about the axes.

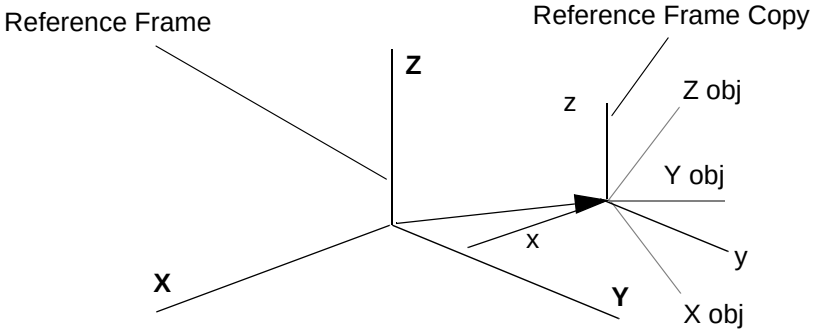


Figure 3-7 Orientation

With the two frames initially coincident, the rotations are performed in a specific order to arrive at the stated orientation. Using a copy of the reference frame is important to prevent inadvertent position changing. That is, if the rotations are conducted about the axes of the reference frame itself, the position and the orientation will change.

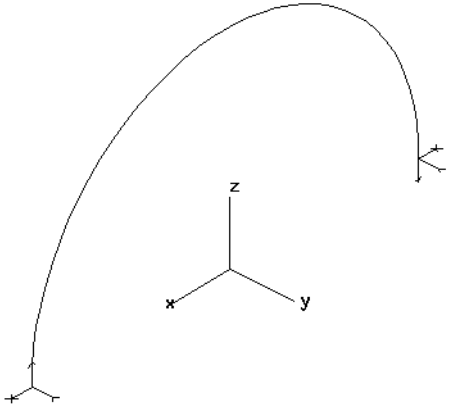


Figure 3-8 Frame rotated about Y axis

Using SilTools, there are three main ways to specify the rotations that describe the orientation of a frame:

- Sequential rotations of the frame about the fixed X, Y, and Z axes of the reference frame copy (called **yaw-pitch-roll**).
- Sequential rotations about the X, Y, and Z axes of the frame's new orientation after each successive rotation (called **Euler angles**).
- A single rotation of the frame about a generalized axis pointing out from the origin of the reference frame copy (called **equivalent angle-axis**).

Within the **Euler** and **fixed** representations, there are 24 combinations for specifying orientations. Use the input representation from the following list which matches your situation, and the SIL function **to_frame**, to convert general orientations to SilTools frames.

xyz_fixed	**yzx_fixed**	**xyx_fixed**	**yzy_fixed**
xyz_euler	**yzx_euler**	**xyx_euler**	**yzy_euler**
xzy_fixed	**zxy_fixed**	**xzx_fixed**	**zxz_fixed**
xzy_euler	**zxy_euler**	**xzx_euler**	**zxz_euler**
yxz_fixed	**zyx_fixed**	**yxy_fixed**	**zyz_fixed**
yxz_euler	**zyx_euler**	**yxy_euler**	**zyz_euler**

Yaw-Pitch-Roll

In SilTools terminology, **yaw**, **pitch**, and **roll** refer to rotation about the X, Y, Z axes (in that order) about a fixed reference frame. In the case of robot end-effectors, the Z axis points outward along the centerline of the flange. Therefore, the roll of the wrist always occurs about the Z axis of the tool or mounting flange (see Figure 3-9).

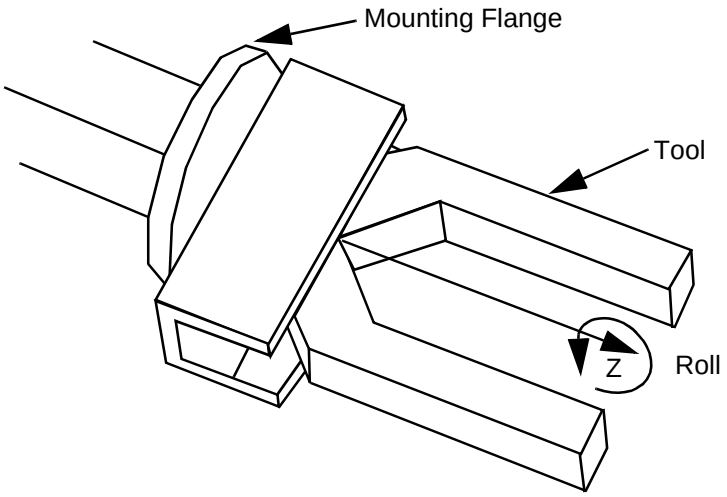


Figure 3-9 Yaw-Pitch-Roll

Yaw-pitch-roll is convenient for describing the orientation of any object's frame. The rotations are performed sequentially about the axes of the initial orientation of the frame and always performed in this order:

1. Yaw (about X).
2. Pitch (about Y).
3. Roll (about Z).

The order in which the rotations are performed is important. In general, a rotation about x followed by a rotation about y followed by a rotation about Z (yaw-pitch-roll) will not produce the same orientation as a rotation about Z, then about Y, then about X (roll-pitch-yaw).

Figure 3-10 shows the difference between a yaw-pitch-roll of (90,90,90) and a roll-pitch-yaw of (90,90,90).

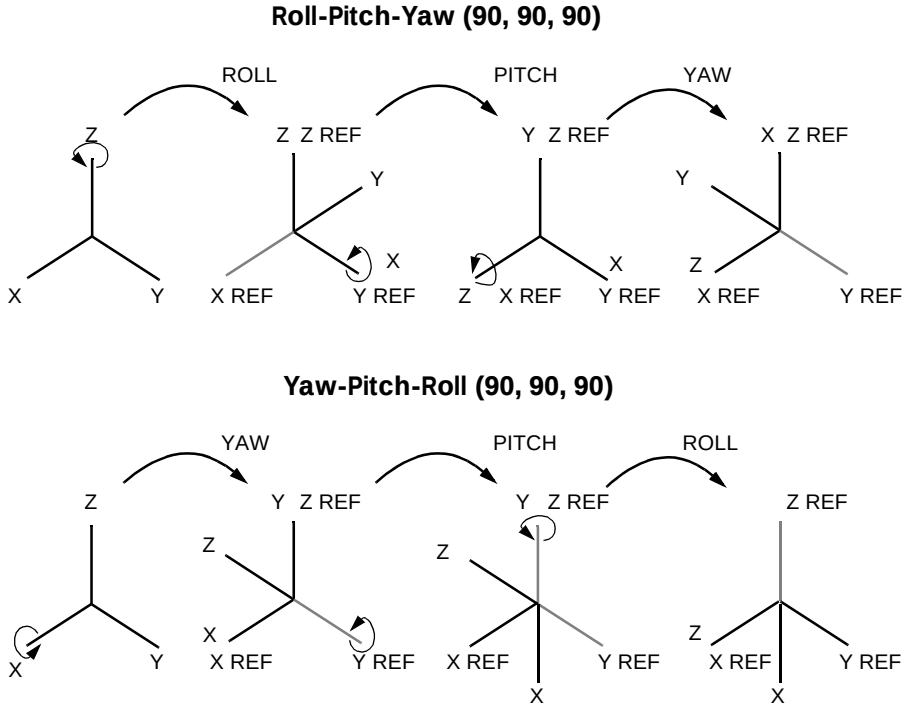


Figure 3-10 Roll-Pitch-Yaw vs. Yaw-Pitch-Roll

For mnemonic reasons the rotations will always be performed in the order in which they are specified. Because X-Y-Z is a familiar order, yaw-pitch-roll is only used in SilTools for rotations about the (fixed) axes of the reference frame copy. Because all three rotations are defined relative to the same initial frame orientation, these rotations are relative to fixed axes. This is a key point since Euler angles are rotations which are not relative to fixed axes.

The geometric type provided by SIL for describing yaw-pitch-roll orientations is **ypr** (yaw-pitch-roll). You may construct a yaw-pitch-roll orientation with the command

mk_ypr(<yaw>,<pitch>,<roll>);

Euler Angles

Euler (pronounced “oiler”) angles are named after a Swiss mathematician, Leonhard Euler (1707-1783), who contributed many important theorems to the science of kinematics. Like yaw-pitch-roll, Euler angles describe orientation by sequential axis rotations. The difference is that the rotations are not about the axes of the fixed reference frame copy as they are with yaw-pitch-roll rotations; they occur about the new axes of the frame after each rotation.

In general, any series of three rotations in which each successive rotation is about one of the new X, Y, or Z axes is a set of Euler angles. For example, one commonly used convention is Z-Y-Z Euler angles. An orientation given in Z-Y-Z Euler angles is the result of first rotating the frame about the Z axis of the reference frame copy with which it is initially coincident, then rotating about the new Y axis and, finally, rotating about the new Z axis. Many six degree of freedom robots have wrists which emulate this Z-Y-Z orientation.

The geometric type provided by SIL for describing Z-Y-Z Euler angle orientations is **zyz** (Z axis, Y axis, Z axis). A Z-Y-Z Euler angle orientation may be constructed with the command

mk_zyz(<rotz1>,<roty>,<rotz2>);

Another Euler angle set is X-Y-Z. An orientation given in X-Y-Z Euler angles is the result of first rotating the frame about the X axis of the reference frame copy with which it is initially coincident, then rotating about the new Y axis and, finally, rotating about the new Z axis.

The geometric type provided by SIL for describing X-Y-Z Euler angle orientations is **xyz** (X axis, Y axis, Z axis). You may construct an X-Y-Z Euler angle orientation with the command

mk_xyz(<rotx>,<roty>,<rotz>);

As with yaw-pitch-roll, the order in which the rotations are performed is crucial in describing orientations using either set of Euler angles.

Equivalent Angle-Axis

One of Euler's theorems states that any orientation may be achieved with an appropriate rotation of the frame about a general axis through the origin of the reference frame copy. This is called the **equivalent angle-axis** rotation.

The equivalent axis of rotation may be represented as a unit vector from the origin of the reference frame copy. The formula for finding a unit vector from a set of XYZ Cartesian coordinates through which the positive axis of rotation passes is

$$u = \frac{a}{|a|}$$

where u is the desired unit vector, a is the Cartesian point in vector form, and

$$|a|$$

is the vector magnitude of a.

For instance, a unit vector through the Cartesian point (1,1,1) is

$$\left(\frac{\sqrt{3}}{3}, \frac{\sqrt{3}}{3}, \frac{\sqrt{3}}{3}\right)$$

A unit vector through the point (1,2,0) is

$$\left(\frac{\sqrt{5}}{5}, \frac{2\sqrt{5}}{5}, 0\right)$$

A unit vector along the X axis is simply (1,0,0). The equivalent angle-axis representation is constructed by multiplying the unit vector of the equivalent axis by the equivalent angle.

The geometric type provided by SIL for describing equivalent angle-axis orientations is **aax** (equivalent angle-axis). You may construct an equivalent angle-axis orientation with the command

mk_aax(<xeq>,<yeq>,<zeq>);

Although it is not easy to determine the appropriate general axis and proper rotation to produce a desired orientation, the equivalent angle-axis representation is useful for producing complex orientations when you know both the axis and amount of rotation. Consider the antenna in Figure 3-11.

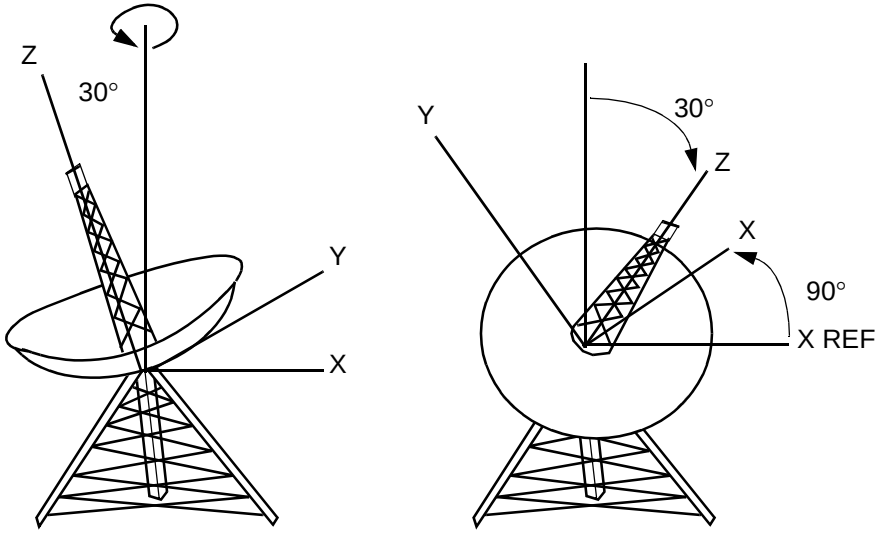


Figure 3-11 Angle-axis orientation

The Z axis of the dish's frame is normal to the dish at its center, and is tilted 30 degrees from vertical in its YZ plane. To rotate the dish 90 degrees while maintaining the same tilt, you must determine the unit vector of rotation along the vertical axis in the dish's frame (which is 0,sin30,cos30). Next, multiply the vector by the desired rotation of 90. The resultant orientation (with respect to the initial orientation) is

[0,45,77.9] as aax

When orientations involve only a single rotation about the X, Y, or Z axis of the reference frame copy, it makes no difference whether you describe them using yaw-pitch-roll, X-Y-Z Euler angles, or equivalent angle-axis. For example, the following commands each describe the same orientation:

```
[0,70,0] as ypr;
[0,70,0] as xyz;
[0,70,0] as aax;
```

Figure 3-12 illustrates that this is not the case for orientations involving more than one principle axis rotation.

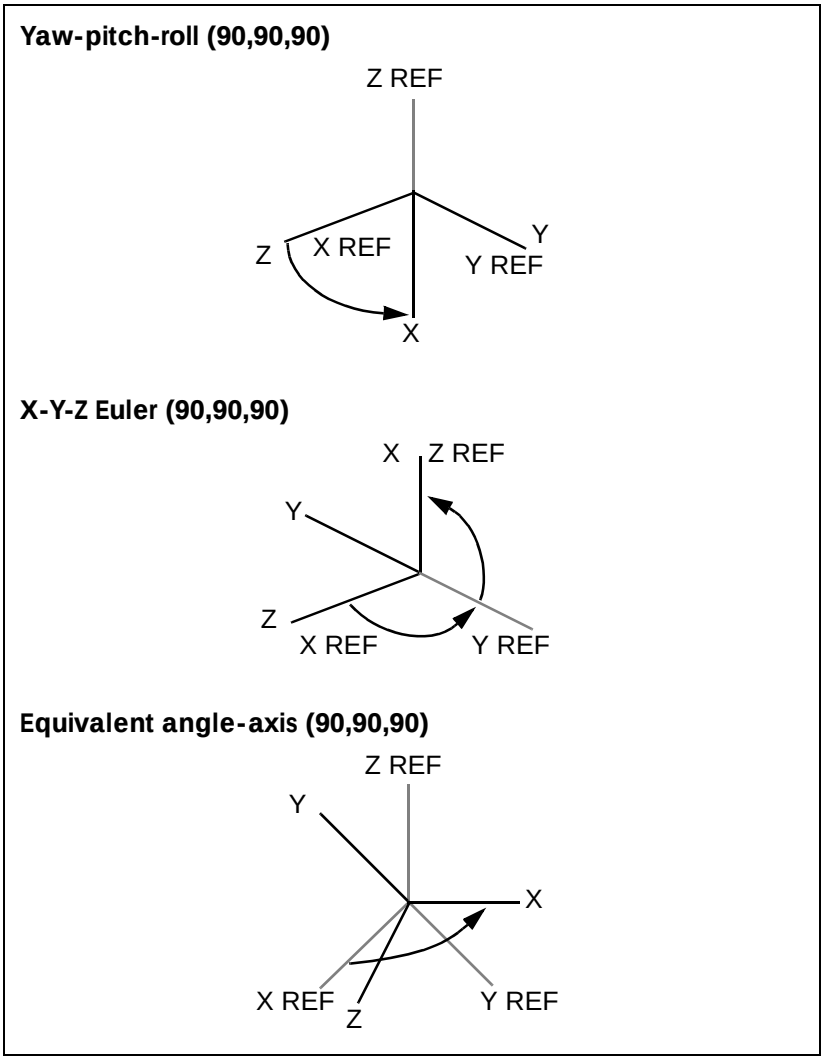


Figure 3-12 Orientations with multiple axis rotations

Poses

Every shape (including World) has an associated local reference frame which is called its **pose**. The pose of the World is the master reference system, and every other shape in the World tree has a pose which is specified relative to the World pose. When you select a reference frame using the menus, the pose of some shape is always selected. The default reference frame is the pose of the World and may sometimes be called the Universe **coordinate system**.

In SilTools, a pose is described using six values that combine its position and orientation (**x**, **y**, **z**, **yaw**, **pitch**, **roll**).

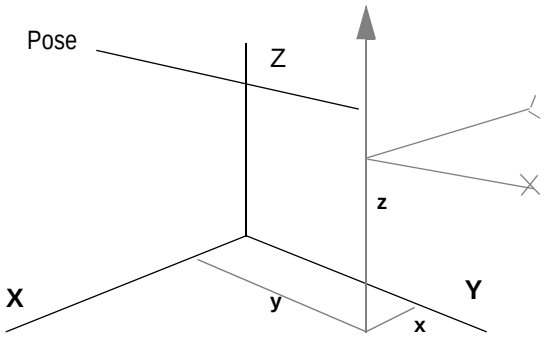


Figure 3-13 Pose

Describing position and orientation is simply a matter of combining a position and orientation using the geometric type **pose**. The general form of the command is

mk_pose(<position>,<orientation>);

where <**position**> and <**orientation**> may be any of the types described above. Either or both position and orientation may be specified. If you omit position, it is assumed to be (0,0,0). Likewise, if you omit orientation, it is assumed to be (0,0,0).

For added convenience, a pose may be specified with six numbers. The first three indicate the Cartesian position, and the last three indicate the yaw-pitch-roll orientation:

mk_pose(<xc>,<yc>,<zc>,<yaw>,<pitch>,<roll>);

This Cartesian yaw-pitch-roll description is the default of poses used in SilTools.

Example 3.2

Some examples specifying poses are

```
mk_pose(mk_sph(1,2,3),mk_ypr(90,0,30);
mk_pose(position_1,mk_xyz(30,45,0));
mk_pose(table_orientation);
mk_pose(30,50,74.2,90,90,0);
```

As an aid in visualizing poses, they can be displayed as frames using the **show** command:

```
show(<pose>);
```

The specified pose will be displayed as a frame whose origin is the point specified by the position component of the pose, and whose axes represent the orientation component of the pose. Poses displayed with the **show** command remain visible as frames only temporarily—they disappear the next time the graphics display is updated.

Geometric Operators

All positions, orientations, and poses are absolute. In other words, the assumed reference is the Universe frame whose pose is the null (absolute) pose described in Cartesian and yaw-pitch-roll terms as (0,0,0,0,0,0).

You may find it convenient to think of poses in relation to reference frames other than the Universe frame. For instance, given a pallet full of parts, it is easier to specify the poses of those parts relative to the frame of the pallet rather than to the Universe frame, especially if the absolute pose of the pallet is unknown beforehand.

Example 3.3

Use the geometric operator **rel** to specify a reference frame. The general command form of the **rel** operator is

<geometric type>rel<pose>;

where the argument preceding **rel** can be any position, orientation, or pose, and the argument following **rel** must always be a pose. The value returned is always an absolute position, orientation, or pose computed from the two arguments. For example, consider a pose of (1,2,3,0,0,0). A position (1,3,2) relative to this pose would be the position (2,5,5) in the Universe frame. That is,

```
mk_crt(1,3,2)rel
mk_pose(1,2,3,0,0,0);
```

returns the Universe position (2,5,5).

Returning to the pallet example, suppose you have defined a pose called **pallet_pose** to represent the pose of the pallet frame relative to the Universe. To place a part on a corner of the pallet four inches in from both sides, you would construct the pose as follows:

```
part_pose:=mk_pose(4*inch,4*inch,0,0,0,0) rel pallet_pose;
```

Assume that the reference frame of the pallet is at the corner. SilTools computes the pose of the part in the frame of the Universe, but you need only specify its pose relative to the pallet pose. If you do not use **rel**, use the following:

```
part_pose:=mk_pose(4*inch,4*inch,0,0,0,0);
```

SilTools assumes that you mean 4 inches along the X axis and 4 inches along the Y axis of the Universe.

Sometimes you know the poses of two frames relative to the Universe, but would like to know the pose of one in the frame of the other. For this, you use the **in_frame** operator:

<geometric type>in_frame<pose>;

where the argument preceding **in_frame** can be any absolute position, orientation, or pose (relative to the Universe), and the argument following **in_frame** is a pose relative to the Universe. The value returned is always a position, orientation, or pose with the pose specified after the **in_frame** operator as its reference instead of the Universe.

Example 3.4

Consider a pose of (1,2,3,0,0,0) and a position (3,2,1). This position in the frame of the given pose would be (2,0,-2). That is,

```
mk_crt(3,2,1)in_frame mk_pose(1,2,3,0,0,0);
```

returns the absolute position (2,0,-2).

The **in_frame** operator is useful if you need to rearrange components of a simulated workcell without changing their poses relative to one another.

Example 3.5

Suppose you have defined conveyor and robot poses relative to the Universe such that the robot can pick parts off the conveyor. And suppose you need to reposition both the robot and conveyor to make room for a new machine, but don't want to change the conveyor's position relative to the robot. Using **in_frame** you may find the conveyor's position in the frame of the robot:

```
conv_in_robot:=conveyor_pose
 in_frame robot_pose;
```

After you have defined the robot's new pose relative to the Universe, the new pose for the conveyor relative to the Universe is

```
con_new_pose:=conv_in_robot rel robot_new_pose;
```

No matter where you decide to put the robot, the new conveyor pose relative to the Universe is always the value of **conv_in_robot** relative to the new pose of the robot. Poses created using **in_frame** are almost always used later as the first argument in a **rel** statement.

Example 3.6

To illustrate the difference between **rel** and **in_frame**, suppose you want to retract the tool of a robot 20 cm along its own Z axis. If the present pose of the tool is called **tool_pose** and the retracted pose is called **retract_pose**, the command to compute the retracted pose is

retract_pose:=mk_pose(0,0,-20,0,0,0)rel tool_pose;

Now you can command the robot to move its tool to **retract_pose** and the tool will appear to retract. If you use the following command instead:

retract_pose:=mk_pose(0,0,-20,0,0,0) in_frame tool_pose;

the pose (0,0,-20,0,0,0) is assumed to be relative to the Universe, and the computed pose is very different from what you intended.

Note that **rel** and **in_frame** are inverse operations. For two poses **a** and **b**:

a rel b in_frame b;

and

a in_frame b rel b;

both return the pose **a**.

Chapter 4

Data Types

This chapter describes the basic data types, including lists, arrays, records, strings.

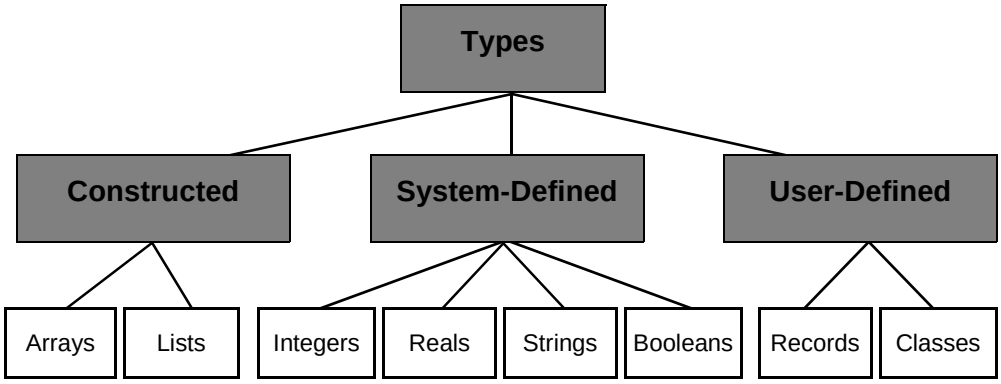


Figure 4-1 Basic SIL data types

NOTE The complete SIL data type structure is shown in Figure 1-5, “Data type classifications” on page 1-11.

Constructed Types

Constructed types are built from existing types using type constructors. Some type constructors are **list_of**, **array_of**, **function** and **procedure**.

- **list_of(integer)** is the type of all integer lists.

  The base type of the type **list_of(integer)** is **integer**. Notice that **list_of(list_of(integer))** is another constructed type with base type **list_of(integer)**. **list of integer** is the alternative syntax for **list_of(integer)**.

  Lists are described on page 4-3.

- **array_of(integer)** is the type of all arrays of integers (regardless of size).

  The base type in this case is **integer**. **darray of integer** is the alternative syntax for **array_of(integer)**.

  Arrays are described on page 4-8.

- **function(real, integer, integer)** is the type of all functions that take two integer inputs and return a real output. Integer division is a function in this type.
- **procedure(real, integer)** is the type of all procedures which expect a real-valued and integer-valued input.

NOTE Procedures and functions are described on page 2-2.

System-Defined Types

SIL system-defined types include the basic scalar types: **integer**, **real**, **boolean**, **string**. Strings are described on page 4-12.

User-Defined Types

User-defined types are created by type definitions:

type <name> = <type expression>;;

Any kind of type expression can be used in a type definition.

Example 4.1

```
type
    age = integer;
    height = real;
    name = string;;
```

Two of the most commonly-used of these types, **record**s and **lrecord**s, are described on page 4-17. Classes are described in Chapter 5, “Classes”.

Lists

This section contains the following topics:

- *List Types*
- *Other List Operations*
- *Destructive List Operations*
- *List Recursion and Iteration*

A **dynamic list** is a sequence of objects, all of the same type, which can grow and shrink during program execution. You can define and manipulate dynamic lists using the traditional Lisp operations: **car**, **cdr**, and **cons**. Examples 4.2 and 4.3 demonstrate the use of the **list** operator as well as **car**, **cdr**, and **cons**.

Example 4.2

In the list creation process, applying the list operator to any number of like-typed operands creates and returns the list consisting of the operand values. For example, the function call

list(88, -3, 0, 10 + 2)

creates the list

[88, -3, 0, 12].

Example 4.3

The **car, cdr**, and **cons** operators may be used in the following fashion:

Assume we have defined the global variable l1 by:

```
l1 == list(88, -3, 0, 10 + 2);
```

The function application

```
car(l1)
```

returns 88, the head of l1. While the call

```
cdr(l1)
```

returns the tail **[-3, 0, 12]** of l1. This does not modify the value of **l1** which is still the list **[88, -3, 0, 12]**. The function call

```
cons(100, l1)
```

returns a new list with head = 100 and tail = l1.

List Types

The base type of a list is the type of the members of the list. The list operations ensure that the base type of a list is well-defined. For example, the call

```
list(1, 2, 'hello world')
```

results in a type mismatch error, since all of the arguments are not of the same type. This seems fairly straightforward until we consider **empty lists** (lists with 0 members). What is the base type of an empty list? To solve this problem in SIL, you need to declare the base type whenever you create an empty list. A call to the empty list constructor has the form

```
emptylist(<type>)
```

where **<type>** is any type expression and indicates the base type of the empty list returned by this call. Of course, you must be able to determine whether or not a list is empty. To check whether or not a list is empty, use the predicate

```
null(<list>)
```

which returns **true** if **<list>** is an empty list (of any base type).

Other List Operations

Besides the basic list operations introduced in "List Types" on page 4-4, SIL provides many other list operations. Example 4.4 illustrates some of these other list operations.

Example 4.4

Assume **l1** and **l2** are lists of the same base type. When this is true,

l1 * l2	returns the result of appending **l1** to **l2**.
length(l1)	returns the length of **l1**.
reverse(l1)	returns the result of reversing **l1**.
select(l1, i)	returns the i-th element of **l1**.

NOTE **select(l1, 0) =** the first element of **l1**.
select(l1, length(l1) - 1) returns the last element of **l1**.
l1 := reversip(l1); reverses a list. The function **reversip** does not allocate any new memory to perform the reverse operation and is more efficient.

Destructive List Operations

All of the list operations discussed above are **non-destructive** functions. This means that they return a value without modifying their inputs as a side effect. By contrast, **set_car** and **set_cdr** are procedures which redefine the **car** and **cdr** of their first argument (illustrated in Example 4.5).

Example 4.5

Assume **l1** is the list **[22, 33, 44, 44]**. When this is true, the procedure call:

set_car(l1, 0)

modifies **l1** by replacing the 22 with 0. The procedure call

set_cdr(l1, list(4, 4, 4))

modifies **l1** by replacing the tail of **l1** with **[4, 4, 4]**.

CAUTION Exercise caution when using destructive operations. Programs that destructively modify a global list may create unpredictable results in other programs which reference this list.

List Recursion and Iteration

The most effective method of demonstrating the use of list recursion is through the use of an example:

Example 4.6

Consider the following two methods for adding up a list of integers. With the recursive method, we first forward reference our function:

```
var sum1: function(integer, list of integer);;
```

We decide to return 0 if the input list is empty. We use the null predicate test for this.

```
function sum1(l: list of integer): integer;
    begin
        if null(l) then sum1 := 0
        else sum1 := car(l) + sum1(cdr(l))
    end;
```

To write an iterative algorithm with the same functionality, a special iterative control structure would be used which enables you to iterate over lists (illustrated in Example 4.7).

Example 4.7

```
function sum2(l: list of integer): integer;
    var accum: integer;
    begin
        accum := 0;
            for k in l do
        accum :=k + accum;
        sum2 := accum
    end;
```

The statement

```
for k in l do
    accum := k + accum;
```

NOTE **k,** the loop control variable, does not need to be declared.

is equivalent to

```
while not null(l) do
begin
    k := car(l);
    l := cdr(l);
    accum := k + accum
end;
```

In Example 4.8, we change **sum2** to take an arbitrary number of integers as input and return their sum. This is slightly different from Example 4.5 where **sum1** expects a single list as input.

Example 4.8

Change **sum2** by typing

```
make_fexpr('sum2');
```

Call **sum2** as follows:

```
SIL> sum2(1,2,3,4,4);
14
SIL> sum2(31,32,33);
96
```

Arrays

Like lists, SIL arrays are also dynamic. This means that arrays can be created during program execution. The call

array_create(<type>, <integer>)

returns an array of base type **<type>** indexed from **0** to **<integer>**. As in Pascal, if **v** is an array and **i** is a valid index, then **v[i]** is an expression whose value is the element of **v** with index **i**, and **v[i] := <term>** sets the index **i** component of **v** to be the value of **<term>**. As with lists, the type of **<term>** must match the base type of **v**, or a type mismatch error will result.

Example 4.9

Here is a typical declaration of an array:

```
var v: darray of integer;;
```

Notice that no memory is allocated to **v** by this declaration (how long should **v** be?) Thus, the expression **v[0]** causes an error.

Next, allocate memory for **v** with

```
v := array_create(integer, 10);
```

Finally, fill **v** with

```
for i := 0 to 10 do
    v[i] := square(i);
```

Example 4.10

This example presents an implementation of a 2D array.

```
type
   row_vector = darray of real;
   matrix3x3 = darray of row_vector;;

row_size == 3;
```

continued on next page

Example 4.10 (continued)

```
row0 == array_create(real, 2);
row1 == array_create(real, 2);
row2 == array_create(real, 2);
for i := 0 to 2 do
   begin
      row0[i] := i * 0.1;
      row1[i] := 1 + i * 0.1;
      row2[i] := 2 + i * 0.1
   end;

mat1 == array_create(darray of real, 2);
mat1[0] := row0;
mat1[1] := row1;
mat1[2] := row2;


function matrix_select(m: matrix3x3; row, col: integer): real;
   begin
      matrix_select := m[row][col]
   end;

procedure matrix_set(m: matrix3x3; row, col: integer; val: real);
   begin
      m[row][col] := val
   end;
```

Example 4.11

This example demonstrates dynamic resizing of an array.

```
type
   employee = record
      name: string;
      age: integer;
      salary: real
      end;;
```

continued on next page

Example 4.11 (continued)

```
number_of_employees == 0;

employee_table == array_create(employee, 100);

procedure add_new_employee(ne: employee);
   var
      temp: darray of employee;
      len: integer;

   begin

   len := length(employee_table);

   {if full, then double length of employee_table … }
   if (len <= number_of_employees) then
      begin
         temp := array_create(employee,
                              2 * number_of_employees);
         {write employee_table to temp … }
         for i := 0 to (number_of_employees - 1) do
         temp[i] := employee_table[i];
         {temp becomes new employee_table … }
         employee_table := temp
      end;

   {add new employee to table … }
   employee_table[number_of_employees] := ne;
   number_of_employees := number_of_employees + 1
   end;
```

Since all SIL arrays are indexed starting with **0, number_of_employees** always indexes the next available slot in **employee_table**.

NOTE The **length** function that applied to lists also applies to arrays.

Unlike Pascal, SIL functions can return arrays as values (illustrated in Example 4.12).

Example 4.12

```
init_table_size == 100;

function make_employee_table(): darray of employee;
   begin
      make_employee_table := array_create(employee,
                                          init_table_size)
   end;
```

sarrays

An **sarray** is a dynamically-allocated array, which can grow and shrink during program execution. You can add items to the **sarray**, and the **sarray** will automatically resize itself to fit the new elements. As with standard arrays, if **s** is an **sarray** and **i** is a valid index then **s[i]** returns the **i**th element of the **sarray**, and **s[i] := <term>** sets the index **i** component of **s** to be the value of **<term>**. Also, like arrays, **<term>** must match the base type of **s**, or a type mismatch error will occur.

The command

emptysarray(<type>)

returns a new **sarray**.

The command

sarray_create(<type>, <integer>);

returns an **sarray** with some number of elements already allocated.

Example 4.13

```
add(s,e);          { add element e to the end of sarray s }
add(s,e,i);        { add at index i }
add(s1,s2);        { append s2 to the end of s1 }
add(s1,s2,i);      { insert at index i}
remove(s,e);       { remove element e from sarray s, shifting
                   following elements down }
remove_at_index(s,i);          { remove at index i}
remove(s,i,j);     { remove between index i and j }
clear(s,i);        { remove after index i, if i = -1 then remove all
                   elements }
```

Strings

This section contains explanations and examples of the following topics:

- *String Comparisons*
- *String Conversions*
- *Other Operations on Strings*
- *lstrings*

Strings are dynamic in SIL.

Example 4.14

The definition

```
msg == 'hello';
```

assigns the length 5 string **hello** to the variable **msg**. Later, we can reassign **msg**'s value by

```
msg := 'goodbye';
```

In the above example, we assign a length 7 string (**goodbye**) to the same variable. Memory allocation for the additional characters is handled automatically. Of course shorter strings can be assigned to **msg**:

```
msg := 'bye';
```

Example 4.15 illustrates other string operations.

Example 4.15

Assume the following definitions:

```
dirname == '/cim/project';
filename == 'smith';
```

We can use infix * to concatenate strings:

```
pathname == dirname * '/' * filename;
```

```
SIL> pathname;
/cim/project/smith
```

We can convert to uppercase by using

```
uc_pathname == uppercase(pathname);
```

```
SIL> uc_pathname;
/CIM/PROJECT/SMITH
```

Similarly, the **lowercase** operator converts uppercase strings to lowercase.

String Comparisons

In SIL, users make lexicographical comparisons using the syntax:

<string> < <string>

Example 4.16

```
employee1 == 'smith, j.';
employee2 == 'smith, z.';
employee3 == 'smithers, a.';
```

then

```
SIL>  employee1 < employee2;
TRUE
SIL>  employee1 < employee3;
TRUE
```

Additionally, we can compare strings using: **<=**, **>**, **>=**, **=**, and **<>**.

The **match** operator compares strings that may contain wildcards:

Example 4.17

```
SIL>  match('smith*', 'smith, j.');
TRUE
```

String Conversions

A string composed of numerals can be converted to an integer by

string_to_integer<string>)

Conversely, an integer can be converted to a string by

integer_to_string(<integer>)

Similarly, we can convert reals to strings and back with

real_to_string(<real>)

and

string_to_real(<string>)

Other Operations on Strings

The function

indx(x:string;n:integer):integer;

extracts the **n**th character from the string, and returns its ASCII code. The following function:

setindx(x:string;n,v:integer);

will set the **n**th character to **v** (ASCII). **indx** and **setindx** start at zero (that is, **indx(x,0)** is the first character in the string). The function

mk_string(n:integer):string;

returns a string of length **n** + 1.

A string is represented internally as a contiguous array of bytes. **indx** and **setindx** give direct access to this representation.

Strings can, of course, be used to describe things other than sequences of textual characters. For example, digitized images with 8 bits per pixel can be represented by strings. Strings can be as large as will fit in the process space of the computer running SIL. For some applications, strings of several megabytes of length will be needed.

Here are some other operations:

function copy(x:string):string;
function substring(x:string;n,m:integer):string;
function length(x:string):integer;
substring(x,n,m); returns the substring of **x**, of length **m**, starting at the **n**th character.

lstrings

Consider the following assignments:

```
x := 'abcdffg';
x := substring(x,2,3)
```

These assignments result in the value of **x** being **'bcd'**. The SIL interpreter will construct a new three-character string for the second assignment. Repeated assignments like these can result in an inefficient consumption of memory. To combat this problem, SIL provides an **lstring** which can be defined as follows:

```
lstring = lrecord
    length:integer;
    contents:string
end;;
```

The length of the contents field of an **lstring** is called its **capacity**. The idea behind this is that only the first length (<**lstring**>) characters of contents (<**lstring**>) are meaningful. The remainder of contents (<**lstring**>) is "spare storage" which may be used if the **lstring** grows in length. For now, we just list some of the primitive operations on **lstring**s. None of these except **copy** allocates new memory—they all re-use existing storage.

Primitive operations on **lstring**s:

```
function mk_lstring(x: string): lstring;
function mk_lstring(x: string; n: integer): lstring;
function copy(x: lstring): lstring; { Allocates a new string }
function substring(x: lstring; n,m: integer): lstring;
function select(x: lstring; n,m: integer): lstring;
function equal(x: lstring; y: string): boolean;
function select(x: lstring; y: integer);
procedure lowercase(x: lstring);
procedure concat_onto(y: string; x: lstring);
function lstr_to_str(x: lstring): string;
function to_lstring(x: string): lstring;
procedure float2lstr(y: real; ls: lstring);
function find(cnx: string; lnx: integer; cny: string; lny: integer):
        integer;
function find(x: string; y: string): integer;
function find(x: lstring; y: string): integer;
function find(x: lstring; y: lstring): integer;
procedure concat_onto(x: lstring; n: char);
```

Example 4.18

```
x:= mk_lstring('abcdffg');
x:=substring(x,2,7)
```

will allocate no new storage.

Records and lrecords

This section describes the user-defined types **record**s and **lrecord**s.

Records are always defined within the scope of a **type** definition at the top level. The syntax follows Pascal:

```
type
    <name> = record
        <field>, ... <field>: <type>;
        ...
        <field>, ... <field>: <type>
    end
```

where **<field>** and **<name>** are identifiers.

Example 4.19

The definition

```
type
    employee = record
        name, boss: string;
        age: integer;
        salary: real
    end;;
```

defines a new data type called **employee**. Objects of type employee are 4-tuples consisting of 2 strings followed by an integer and a real.

Unlike Pascal **record**s, defining a **record** in SIL automatically defines a constructor function that enables you to create **record**s in a single statement. The name of the constructor function adds the prefix **mk**_ to the name of the **record** (illustrated in Example 4.20).

Example 4.20

The statement

```
empl1 == mk_employee('smith', 'jones', 29, 30000.00);
```

defines **empl1** to be an object of type employee with the indicated field values. We can access the fields of **empl1** as follows:

```
empl1.boss;
```

or

```
salary(empl1);
```

and we can alter the fields of **empl1** as follows:

```
empl1.age := 30; {happy b'day!!}
```

or

```
dset_age(empl1, 30);
```

SIL provides a special syntax for constructors. The following constructor:

```
[<expression>...<expression>] as <type>;
```

is equivalent to

```
mk_<type> [<expression>...<expression>]
```

For example,

```
empl== ['smith; 'jones', 29, 30000.00] as employee;
```

Unlike Pascal, SIL functions can return **record**s as values. A simple example is the definition of a customized constructor. Defining customized constructors is a good technique if several fields have standard default values (see page 4-19).

```
function mk_employee(name: string; age: integer): employee;
  begin
  mk_employee := mk_employee(name, 'jones', age, 30000.00)
  end;
```

lrecords

Record parameters are passed by value. This means that a function/procedure that is passed a **record** as an input actually makes a private copy of the **record** input before it modifies any of its fields.

Example 4.21

```
procedure change_salary(empl: employee; amt: real);
   begin
      empl.salary := salary(empl) + amt
   end;
```

Assume that

```
empl1 == mk_employee('smith', 'jones', 29, 30000.00);
```

We attempt to give Smith a little raise:

```
change_salary(empl1, 20000.00);
```

But the following week Smith is disappointed to find no change in his paycheck:

```
SIL>  empl1.salary;
30000.00
```

In SIL, **record**s are used to represent non-mutable entities such as vectors, complex numbers, etc. In Example 4.22, a **record** is used to represent a complex number.

Example 4.22

```
type
complex = record
     rpart, ipart: real
end;;

z == mk_complex(1, 2);
```

In this case, **z** is the complex number **1 + 2i**, and **z** is non-mutable in the sense that modifying a field of **z** modifies the identity of **z**. By contrast, modifying Smith's salary in Example 2.4 does not modify Smith's identity—he/she is still the same person, just richer.

In SIL, **lrecord**s are used to represent mutable structures like employees. An **lrecord** is just a pointer to a **record**—**lrecord** parameters are passed by reference rather than by value. This means that a function/procedure only gets a pointer to an **lrecord**, not a private copy.

Example 4.23

Defining an **lrecord** follows the same syntax as defining a **record**:

```
type
  employee = lrecord
               name, boss: string;
               age: integer;
               salary: real
             end;;
```

In every other respect, **record**s and **lrecord**s are syntactically indistinguishable. Thus, we can proceed as before:

```
procedure change_salary(empl: employee; amt: real);
  begin
    empl.salary := salary(empl) + amt
  end;

empl1 == mk_employee('smith', 'jones', 29, 30000.00);

change_salary(empl1, 20000.00);
```

This time Smith can go ahead with those sudden secret travel plans:

```
SIL>  empl1.salary;
50000.00
```

Chapter 5

Classes

This chapter describes classes, objects, inheritance, how objects are viewed relative to each other, and how to manipulate the views.

Object-Oriented Terminology

An **object** is similar to an **lrecord**. Wherever an **lrecord** might be used, an object can also be used. Thus, objects can be used to represent entities with mutable properties such as devices, people, factories, organizations, etc. The main feature that distinguishes objects from **lrecord**s is **inheritance**. Briefly, two objects, **A** and **B**, belonging to different types (**classes**), can be related in such a way that all properties of **A** are also properties of **B**. We say that **B** *inherits* **A**'s properties. Logically, we can interpret this to mean that **B** is a specialization of **A** (or **A** is a generalization of **B**), since **B** may have additional properties apart from those inherited from **A**.

The advantage of inheritance is that you don't have to build the object **B** from the ground up. By declaring **B** to be a specialization of **A**, the properties of **A** automatically become properties of **B**. This can be a huge time-saver if **A** is a system-defined object with lots of useful, but low-level, properties. For example, **B** might be a tin can with physical properties such as weight, material, pressure, etc., whereas **A** might be a cylinder with geometric and graphical properties such as tangent plane at a point, boundary representation, mouse selectable, etc. Clearly, a scientist or engineer simulating a tin can should be expected to define the domain-specific properties of the tin can, like weight and pressure, but should not be expected to define the lower-level properties of a cylinder, even though these properties are necessary for displaying and manipulating the tin can in simulation. Because SilTools provides a type (class) cylinder, our scientist/engineer need only define **A** to be a cylinder, and declare **B** to be a specialization of **A**.

Classes

The definition of a class in SIL is very similar to a Pascal (or SIL) record definition:

```
type <new-class> = class
  superclass:<class1>;
  superclass:<class2>;

  …
  <instance-var-1>:<type1>
  <instance-var-2>:<type2>

  …
  end;;
```

Example 5.1 introduces the concept of class using object-oriented terminology.

Example 5.1

Here is an example of a class definition:

```
type employee = class
    name: string;
    ssn: integer;
    salary: real;
    end;;
```

As with records and **lrecord**s, the constructor **mk_employee** is automatically defined:

```
jones == mk_employee('jones', 558112937, 30000.00);
smith == mk_employee('smith', 443991875, 42500.00);
```

In this example, **employee** is a class, while **jones** and **smith** are objects, and '**jones**', **558112937**, and **30000.00** are attributes of the object **jones**.

continued on next page

Example 5.1 (continued)

We can write functions or procedures that operate on employee objects like any other data types:

```
function monthly_salary(e: employee): real;
        begin
        monthly_salary := salary(e)/12
        end;

standard_rate == 0.07;

procedure grant_standard_raise(e: employee);
        begin
        e.salary := salary(e) + standard_rate * salary(e)
        end;
```

In the parlance of object-oriented terminology, we call **monthly_salary**, and **grant_standard_raise** *methods*. In SIL, sending a message to an object is the same as applying a function symbol to a list of arguments. For example, some object-oriented languages would regard the identifier **monthly_salary** as a message which, when sent to an object, invokes the method **monthly_salary**. In this case, the syntax might look like

```
send_message(jones, "monthly_salary)
```

The advantage of **send_message** is that it provides a way to implement polymorphism (because the same message could be interpreted in different ways by different objects). Because SIL is already a polymorphic language, we can abandon **send_message** and simply apply methods directly to objects:

```
monthly_salary(jones)
```

or equivalently

```
jones.monthly_salary.
```

Example 5.1 (continued)

Thus

```
SIL>  monthly_salary(jones);
2500.000000
SIL>  grant_standard_raise(jones);
OK
SIL>  monthly_salary(jones);
2675.000000
```

Inheritance

Example 5.2 introduces the principles of inheritance. In this example, we will continue to use the material from Example 5.1.

Example 5.2

For now, assume

```
account == string;
project == string;
```

We introduce a new class which is a subclass of the employee class defined earlier:

```
type manager = class
    superclass: employee;
    leader_of: project;
    staff: list of employee;
    end;;
```

The class **manager** is a subclass of **employee** because, conceptually, all managers are employees.

Example 5.3

We can make managers out of employees as follows:

```
team1_leader == mk_manager(smith, 'release V', list(jones));
```

As you might expect, we can define new methods, and apply them as before:

```
function staff_size(m: manager): integer;
    begin
    staff_size := length(staff(m))
    end;

procedure remove_from_staff(m: manager; e: employee);
    var
    new_staff: list of employee;
    begin
    new_staff := emptylist(employee);
    for x in staff(m) do
    if name(x) <> name(e) then new_staff := cons(x, new_staff);
    m.staff := new_staff
    end;
```

and so

```
SIL>  staff_size(team1_leader);
1
SIL>  remove_from_staff(team1_leader, jones);
ok
SIL>  staff_size(team1_leader);
0
```

In Example 5.3, **team1_leader** specializes **smith**; therefore, all employee methods can be applied to **team1_leader** without explicitly coercing or casting **team1_leader** to the class employee. This process is called inheritance because **team1_leader** inherits all methods and attributes of **smith**:

Example 5.4

```
SIL> monthly_salary(team1_leader);
3541.666748
```

In addition, the attributes of **smith** can be accessed through **team1_leader**:

Example 5.5

```
SIL> ssn(team1_leader);
443991875

SIL> name(team1_leader);
smith
```

Because all managers are employees, it always makes sense to apply employee methods to managers. But because some employees are not managers, it does not always make sense to apply manager methods to employees:

Example 5.6

```
SIL> staff_size(smith);
error: type mismatch in application of the
operator STAFF_SIZE
```

Example 5.7 illustrates how the above method can be followed to add more classes, objects, and methods:

Example 5.7

```
type
    sales_person = class
    superclass: employee;
        accounts: list of account;
    end;

    programmer = class
        superclass: employee;
        projects: list of project;
        languages: list of string;
        boss: manager;
        end;;

procedure add_to_staff(p: programmer; m: manager);
    begin
    p.boss := m;
    p.projects := cons(leader_of(m), projects(p));
    m.staff := cons(p, staff(m));
    end;
```

Thus, if jones is a programmer working for smith, then we can set this up as follows:

```
var default_manager: manager;;
    programmer2==mk_programmer(jones, emptylist(project),
                        list('lisp', 'c', 'pascal'),
                        default_manager);

add_to_staff(programmer2, team1_leader);

SIL>  projects(programmer2);
[LIST: release V]

SIL>  name(boss(programmer2));
smith

SIL>  name(programmer2);
jones
```

Example 5.8

We can define subclasses of subclasses:

```
type
    student_programmer = class
        superclass:programmer;
        school: string;
        gpa: real;
        end;;
```

In this case, **student_programmer** is a subclass of **programmer**, but because **programmer** is a subclass of **employee**, we can infer that **student_programmer** is also a subclass of **employee**. For example, suppose **jones** is a Stanford student working for the summer:

```
student1 == mk_student_programmer(programmer2,
                                  'stanford', 2.9);
```

All **programmer2** attributes can be accessed through **student1**:

```
SIL> student1.languages;
[LIST: lisp,c,pascal]

SIL> student1.projects;
[LIST: release V]
```

but also, all attributes of **jones** can be accessed through **student1**:

```
SIL> SIL> student1.name;
jones

SIL> SIL> student1.salary;
32100.00
```

Similarly, employee and programmer methods can be applied directly to **student1**:

```
SIL> monthly_salary(student1);
2675.00
```

Example 5.9

We can derive methods for student programmers in the expected way:

```
min_gpa == 3.0

function
is_good_lisp_programmer(s:student_programmer):boolean;
    begin
    is_good_lisp_programmer:=member('lisp',languages(s)) and
                                        (gpa(s) > min_gpa)
    end;
```

Thus

```
SIL>  is_good_lisp_programmer(student1);
FALSE
```

As expected, these methods cannot be applied to generalizations of **student1**:

```
SIL>  is_good_lisp_programmer(smith);
error: type mismatch in application of the
operator IS_GOOD_LISP_PROGRAMMER
```

Views

This section contains the following topics:

- *Changing Views*
- *The as_view Operator vs. the to_view Operator*

Preceding sections showed how objects can be related to each other through specialization/generalization. This section defines a new relation between objects, called **referential equivalence**, that extends specialization/generalization.

Example 5.10

In this example, we define a new subclass of **employee** unrelated to the other subclasses:

```
type foreign_employee = class
    superclass: employee;
    visa_status: string;
    languages: list of string;;
    end;;
```

Assume Bob Wong is a new foreign student programmer hired by the company. This is how we might define the relevant objects representing Bob:

1. As an employee:

```
wong == mk_employee('Wong', 667213344, 25000.00);
```

2. As a foreign employee:

```
f_emp12== mk_foreign_employee(wong,'student visa',
            list('English', 'Cantonese'));
```

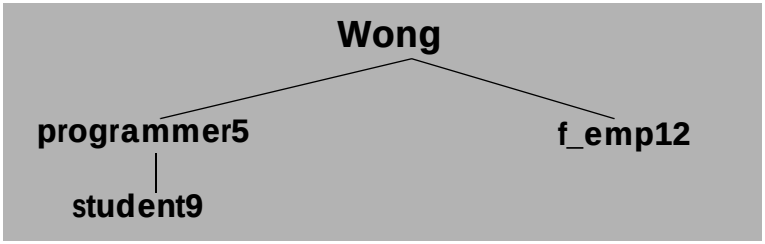
3. As a programmer:

```
programmer5==mk_programmer(wong,
list(leader_of(team1_leader)),
list('pascal', 'lisp', 'c'), team1_leader);
```

4. As a student:

```
student9 == mk_student_programmer(programmer5,
            'Berkeley', 3.2);
```

Example 5.10 defined the student programmer (**student9**), the programmer (**programmer5**), the foreign employee (**f_emp12**), and the employee (**wong**). In fact, all of these objects represent the same person (dynamic entity), but from different points of view. For this reason, objects are sometimes referred to as views.



Two objects are **referentially equivalent** if they are both views of the same entity. Clearly, if object **A** generalizes object **B**, then **A** and **B** are referentially equivalent. But two objects can be referentially equivalent *without* one generalizing the other. In our example, **f_emp12** and **student9** are referentially equivalent, but neither generalizes the other.

The list of all views referentially equivalent to an object is given by the function **views**. The **views** function returns a list of universals (objects, like any other SIL data, can be cast to and from universals). The list of classes to which these views belong is given by the function **classes**. This is a list of **ntypes**. The class of an object is given by the function **my_class**.

Example 5.11

The list of all views of an object is given by the **views** function:

```
SIL>  views(wong);
[LIST:[UNIVERSAL:[Berkeley,3.200000]
OF_TYPE STUDENT_PROGRAMMER],
[UNIVERSAL: [[LIST: release 4.3],
LIST: Pascal,Lisp,C],
<smith>] OF_TYPE PROGRAMMER]
[UNIVERSAL: [student visa,
[LIST: English,Cantonese]]
OF_TYPE FOREIGN_EMPLOYEE],
[UNIVERSAL: [Wong,667213344,25000.000000]
OF_TYPE EMPLOYEE]]
```

continued on next page

Example 5.11 (continued)

The list of all classes of views of an object is given by classes:

```
SIL> classes(wong);
[LIST:STUDENT_PROGRAMMER,PROGRAMMER,
FOREIGN_EMPLOYEE,EMPLOYEE]
```

The function **my_class** returns the class of a view:

```
SIL> for i in views(wong) do writeln(my_class(i));
STUDENT_PROGRAMMER
PROGRAMMER
FOREIGN_EMPLOYEE
EMPLOYEE
```

Changing Views

"Object-Oriented Terminology" on page 5-1 showed how methods and attributes of an object **A** can be used by specializations of **A** without specifically coercing to the class of **A**. Because referentially equivalent objects represent the same entity, we would like all views of **A** (i.e., not just the specializations of **A**), to be able to use the methods and attributes of **A**. Doing this requires changing views using the **as_view** or **to_view** infix operator:

```
<object> as_view <class>
<object> to_view <class>
```

Example 5.12

As stated before, we can't apply student programmer methods to programmers:

```
SIL> is_good_lisp_programmer(programmer5);
error: type mismatch in application of the
operator
IS_GOOD_LISP_PROGRAMMER
```

continued on next page

Example 5.12 (continued)

But since we know that **programmer5** is just another view of **student9**, we can apply **is_good_lisp_programmer** if we first change views:

```
SIL> is_good_lisp_programmer(programmer5 as_view
     student_programmer);
TRUE
```

Similarly, we can access the attributes of **f_emp12** through **student9** by first changing views:

```
SIL> languages(student9 as_view foreign_employee);
[LIST: English,Cantonese]
```

The as_view Operator vs. the to_view Operator

When **<object>** has no view in **<class>**, **<object> as_view <class>** generates an error message while **<object> to_view <class>** returns a null object which can be tested for using the **nul** predicate (illustrated in Example 5.13).

Example 5.13

```
SIL> programmer5 as_view sales_person;
error: attempt to change to incompatible
view:
SALES_PERSON
SIL> thing == programmer5 to_view sales_person;
TRUE
SIL> nul(thing);
TRUE
```

Multiple Inheritance

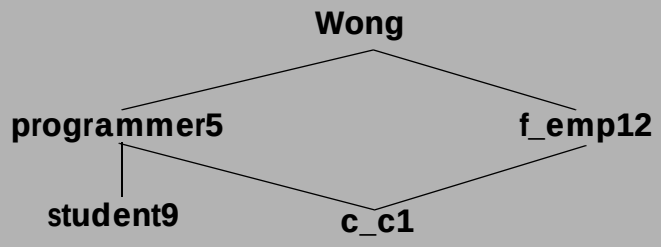
Example 5.1 on page 5-2 shows a class having several superclasses (**student_programmer** which had **programmer** and **employee** as superclasses). In this situation, however, it was possible to identify one of these superclasses, **programmer**, as the immediate superclass of **student_programmer**. This means that all other superclasses of **student_programmer** were also superclasses of **programmer**.

In SIL, it is possible to define a class with two immediate superclasses. For example:

Example 5.14

```
type chinese_c_programmer = class
      superclass: foreign_employee;
      superclass: programmer;
      years_c_experience: integer;
      end;;
c_c1 == mk7_chinese_c_programmer(f_emp12, programmer5, 2);
```

The network of views representing Bob Wong is depicted as follows:



Of course, the methods and attributes of programmers and foreign employees can be used by **c_c1** without explicitly changing views:

```
SIL>  visa_status(c_c1);
student visa

SIL>  projects(c_c1);
[LIST: release 4.3]
```

Multiple inheritance can be used only when the superclasses given for a new class were derived from some common ancestor.

Ambiguity

Accessing the language attributes of **c_c1** causes some ambiguity. It is unclear whether to expect programming languages or spoken languages to be returned.

In this example, methods are applied to the second generalization before the first:

Example 5.15

```
SIL> languages(c_c1);
[LIST: Pascal,Lisp,C]
```

There is no satisfactory rule for deciding how to make messages less ambiguous. Ambiguous messages should be avoided or you should explicitly change views. For example:

Example 5.16

```
SIL> languages(c_c1 as_view foreign_employee);
[LIST: English,Cantonese]
```

IMPORTANT	It is our experience that the availability of **as_view** and **to_view**, combined with the dangers of multiple inheritance, makes multiple inheritance an unsatisfactory choice for most applications.

Using apply on Views

"Views" on page 5-9 showed how the methods and attributes of an object can be accessed by any referentially equivalent object by performing the appropriate view change (using **to_view** or **as_view**). When using **to_view** or **as_view**, the class of the new view must be known in advance. An expression like

foo(student9 to_view cadr(views(x))

where **x** is a variable will cause an error. We can put off the view change until runtime by using **apply**:

apply("<method>, <object>, <expression>… <expression>);

Example 5.17

```
SIL> apply("monthly_salary, programmer5);
[UNIVERSAL: 2083.333252 OF_TYPE REAL]
```

The **apply** operator scans the list of views in the reverse order in which the views were created, searching for an object that can respond to the desired method. Thus **apply** implements late binding of methods to messages—the method is determined at runtime, not compile time. **Runtime** denotes the time at which code executes, while **compile time** denotes the time at which code is read in—whether or not it will be compiled or interpreted. The **apply** operator searches views of its first argument. If the first argument is a universal which, at runtime, turns out to be an object, the view search will still take place.

The **applyn** operator works in the same way as **apply**, but returns a failure indicator when no method is found, rather than generating an error. Use **is_fail** to test for failure.

NOTE	**apply** provides the kind of late binding which underlies the SmallTalk and Objective C object systems. An alternative SIL late binding mechanism which resembles the C++ virtual function facility is described in “Abstract Classes” on page 5-19. We recommend this mechanism over using **apply**. The reasons for this are explained in “Using Methods Instead of apply” on page 5-23.

View Manipulation

Two simple operators are provided for directly manipulating the views of an object: **splice** and **remove_this_view**.

The **splice** operator simply appends the views of **object1** onto those of **object2**. So, **object1** and **object2** are unified—they become referentially equivalent. **object1** may not be spliced onto **object2** if any view of **object1** has the same class as a view of **object2**.

The **splice** operator works like this:

splice(<object1>,<object2>);

Example 5.18

```
type chess_player = class
    rating: real;
    uscf_chapter: string;
    end;;
```

Then, if **student9** is a chess player as well as a student and an employee, we can add this data as follows:

```
splice(mk_chess_player(1700,'san francisco'),student9);
```

In Example 5.18, chess playing and employment are non-interacting properties, so there is no need to define a class of chess-playing employees since you can splice chess data as needed onto individual students who play chess.

The **remove_this_view** operator works like this:

remove_this_view(<object>);

For example, if **student9** in Example 5.18 gives up chess:

Example 5.19

After issuing this command, **student9** will no longer have a **chess_player** view:

remove_this_view(student9 as_view chess_player);

The **remove_this_view** operator will generate an error if the class of any other view of the object is a subclass of the class of the view being removed. If this restriction were not observed, objects with dangling superclass pointers would result.

A view which has been removed should not be referenced after its removal. For example:

Example 5.20

```
chs==mk_chess_player(1700,'san francisco');
splice(chs,student9);
remove_this_view(chs)
```

The resulting value of **chs** is a “dead view”, which should not be referenced in subsequent code.

Abstract Classes

This section describes the abstract class facility. Topics in this section include

- *Installation of Methods*
- *Using Methods Instead of apply*
- *C++*
- *Additional Methods Primitives*

The abstract class facility provides the same sort of functionality as C++ virtual functions—you can define abstract classes whose methods can be implemented by a variety of concrete classes. The facility is more flexible than anything available in C++ in that it allows dynamic modification of the implementing classes and methods of an abstract class. Abstract classes can also be spliced on to pre-existing concrete classes, allowing abstractions to be layered onto existing bodies of concrete code.

Example 5.21 introduces abstract classes by showing a conventional example—an "abstract stack" class.

Example 5.21

```
type astack = class
  push: method(ob,ob);
  ipop: method(ob);
  empty: method(boolean);
  on_underflow: method(ob);
  end;;
```

NOTE This example will be continued on the next page, after the following information.

The method fields are slots which hold operators on **astack**, just as ordinary fields of a class hold data. The usage

method(<return_type>,<input_type$_1$>,... <input_type$_n$>)

specifies a "method" which can be applied to inputs of types **astack**, **<input_type$_1$>…<input_type$_n$>**, and will return the given return type. So, for example, **push** takes an **astack** and an **ob**, and returns an **ob**. The first argument to any method is the class for which the method is defined, so it need not be specified explicitly. It is for this reason that we write **method(ob,ob)** rather than the redundant **method(ob,astack,ob)**.

Now, the method slots in a class definition are filled by ordinary SIL functions which take a view of the **astack** as first argument. For example, the operator installed in the **push** slot will be a procedure which takes a view of an **astack** as its first argument, and an **ob** as its second. The intent of this should become clear as we proceed with this example.

Example 5.21 (continued from previous page)

Now, we define the concrete class **lstack**:

```
type lstack = class
    superclass:astack;
    goods:list of ob;
    end;;
```

Here are some of its methods:

```
procedure push(x:lstack;y:ob);
    begin
    x . goods := cons(y,x . goods);
    end;

function pop(x:lstack):ob;
    begin
    if null(goods(x)) then pop := nil else
        begin
        pop := car(goods(x));
        x .goods := cdr(goods(x));
        end;
    end;

function empty(x:lstack):boolean;
    begin
    empty := null(goods(x));
    end;
```

Installation of Methods

Installation of methods is done using the following primitives. If **a** is a particular **astack**, which is also an **lstack**, we can set the method **push** in **a** to be **push** on the **lstack**:

```
a == mk_astack();
l == mk_lstack(a,emptylist(ob));
set_method(a,"push,"push,list(lstack,ob));
```

That is, when **push** is called on **a,** it "delegates" the work to the **push** variant on **lstack**. So,

```
push(a,x);
```

is equivalent in effect to

```
push(a as_view lstack,x);
```

Example 5.22

```
a == mk_astack();
l == mk_lstack(a,emptylist(ob));

set_method(a,"push,"push,list(lstack,ob));

function pop(x:astack):ob;
      begin
      if empty(x) then
          begin
           if method_defined(x,"on_underflow) then on_underflow(x);
          pop := nil;
          end
      else pop := ipop(x);
      end;
```

As illustrated above, the operator

```
method_defined(x:<any type>;y:id);
```

determines whether the given method has been installed in **x**.

The following operator makes an **astack** with the **lstack** implementation:

```
function mk_lstack(): astack;
    var a: astack; l: lstack;
    begin
    a := mk_astack();
    l := mk_lstack(a,emptylist(ob));
    set_method(a,"push,"push,list(lstack,ob));
    set_method(a,"ipop,"pop,list(lstack));
    set_method(a,"empty,"empty,list(lstack));
    mk_lstack := a;
    end;
```

Note that no method is assigned to **on_underflow**. A user of **astack** is free at any time to execute a **set_method** to install a method for underflow. For example:

Example 5.23

```
a1 == mk_lstack();
a2 == mk_lstack();

procedure yell(x:astack);
    begin
    error('stack underflow!!!');
    end;

set_method(a2,"on_underflow,"yell,list(astack));
```

Then

```
SIL>  pop(a1);
ok
SIL>  pop(a2);
stack underflow!!
Error>
```

Consider what we have done in Example 5.23. **astack** is abstract, because no aspect of its implementation is specified. We have given one concrete implementation (**lstack**), but there could be many others. Code that makes use of **astack**s will work with any concrete implementation.

Using Methods Instead of apply

In earlier versions of SilTools, you needed to use this kind of code to implement abstract classes in SIL:

```
procedure pop(x: astack);
    begin
    apply("pop1,x);
    end;
```

Here, the manner of **pop** done depends on the views that **x** has at runtime. Using methods instead of **apply** has two advantages:

1. Invoking a method is faster than performing an **apply**—it only involves a couple of pointer chases to find the implementation of a method rather than a search.
2. The method style gives the builder of an object control of the methods installed into the object's abstract views because this installation is done by explicit uses of **set_method**.

As a result, the user of **astack** need not worry about views being added later that might have a rogue **pop** operator.

C++

SIL abstract classes and their methods resemble C++ classes with virtual functions, but are considerably more flexible. On the other hand, the SIL **apply** construct resembles normal messaging in objective C or SmallTalk.

On the whole, abstract classes are both the cleaner and the more efficient alternative.

Additional Methods Primitives

The following are more primitives for methods.

```
pmethods(x:<any_type>);
```

prints out the methods currently installed in **x**. This is useful for debugging.

```
define_method(astack,lstack,"ipop,"pop);
```

Instead of installing a method into any particular **astack**, the preceding use of **define_method** defines a standard method to use for **ipop** for any object that is an **astack** implemented by an **lstack**. For **astack a**:

```
use_methods(a,lstack);
```

installs all of the standard methods for **astack** associated with **lstack** into **a**.

An advantage of **use_methods** is that it saves space by just putting a pointer to a block of methods associated with the **lstack** class into **a**. Instead of needing two words per method in **a**, this requires just three words for the whole collection of methods.

Usually, the method machinery is used to install the methods of a concrete class into the method store of an abstract view; so **use_methods** is the typical primitive to use rather than the more direct and low level **set_method** construct.

For example, our implementation of **lstack**s might include the following:

Example 5.24

```
define_method(astack,lstack,"push,"push);
define_method(astack,lstack,"empty,"empty);
define_method(astack,lstack,"pop,"pop);

function mk_lstack();
    var a:astack,l:lstack;
    begin
        a := mk_astack();
        l := mk_lstack(a,emptylist(ob));
        use_methods(a,lstack);
    end;
```

When the abstract and concrete methods have the same name, you need not repeat the name in the **set_method** or **define_method** construct. For example:

```
define_method(astack,lstack,"push);
```

is equivalent to

```
define_method(astack,lstack,"push,"push);
```

and

```
set_method(a,"push,list(lstack));
```

is equivalent to

```
set_method(a,"push,"push,list(lstack));
```

Finally

```
define_methods(astack,lstack);
```

means that the standard **astack** methods associated with **lstack** are those operators on **lstack** with the same names as the **astack** methods. So:

```
define_methods(astack,lstack);
```

is equivalent to

```
define_method(astack,lstack,"push);
define_method(astack,lstack,"empty);
```

The **pop** method does not get installed by **define_methods** because **ipop** is the abstract method name, while **pop** is the implementation name.

Rule 5.1

To remember the argument order for the above primitives, an easy rule is:

Abstract information always precedes the concrete information in the argument order.

Methods can be declared to be tasks rather than procedures by using the keyword **tmethod** rather than **method**.

Example 5.25

To turn a robot into a movable entity without rewriting the original code:

```
type movable_entity = class
    move:tmethod(ob,point);
    end;;
```

continued on next page

Example 5.25 (continued)

```
task move(x:robot;y:point);
    begin
    moveto(select(x,"linkn),y);
    end;

function mk_movable(r:robot):movable_entity;
    var mv:movable_entity;
    begin
    mv := mk_movable_entity();
    splice(mv,r);
    set_method(mv,"move,list(robot,point));
    mk_movable := mv;
    end;
```

Example 5.25 shows how abstract classes can be added onto existing objects. This means that old SIL classes can be given new and cleaner abstract interfaces without rewriting the old code.

This is one of the many differences to C++. In C++, an abstract class must be designed before its implementation (which must be a derived class). This prevents the kind of retrofitting shown above.

Here is another simple working example:

Example 5.26

```
{ the abstract class:character stream }

type cstream = class
    mode:id; { "closed,"input,"out,"append }
    peeked_char:integer;
    open:method(ob,string);
    close:method(ob);
    get:method(integer);
    put:method(ob,integer);
    end;;
```

continued on next page

Example 5.26 (continued)

```
function mk_cstream():cstream;
    begin
    mk_cstream := mk_cstream("closed,0);
    end;

{ a concrete character stream : files }

type file_cstream = class
    superclass:cstream;
    file_of:text;
    end;;

procedure open(x:file_cstream;md:string);
    begin
    open(file_of(x),md);
    x . mode := intern(md);
    end;

procedure close(x:file_cstream);
    begin
    close(file_of(x));
    x . mode := "closed;
    end;

function get(x:file_cstream):integer;
    begin
    get := read_char(file_of(x));
    end;

define_methods(cstream,file_cstream);

function mk_file_cstream(x:string):cstream;
    var cs:cstream;
    begin
    cs := mk_cstream();
    mk_file_cstream(cs,mk_file(x));
    use_methods(cs,file_cstream);
    mk_file_cstream := cs;
    end;
```

Chapter 6

Programming the User Interface

The user interface consists of background panel, *Graphics Window*, top bar (menu bar), tool bar, Quick Access and *Quick Pick Window*. In addition to this, many panels provide custom functionality to a product.

The mnode Class

This section describes the **mnode** class. The word **mnode** comes from "node in the menu tree." **mnode** is an abstract class, and is the class of all screen items (widgets). Actual widgets are built by subclassing and/or splicing an **mnode**. To use the information in this chapter effectively, you should be familiar with widgets. Refer toChapter 7, "Customizing the Menu Interface" in the *SilTools User's Manual*, available from SILMA, Division of Adept Technology, Inc.

Widgets

There are two aspects of widgets: **appearance** and **behavior**. Every widget has a panel view for visual representation.

Appearance

Appearance is defined as how the widget will be displayed on the screen. There are two categories: **container widgets** (widgets with children) and **primitive widgets** (leaf widgets).

Table 6-1 describes the kinds of container widgets.

Widget Kind	Description
top_panel_kind	Main top-level window (top panel).
item_panel_kind	Secondary top-level window (item panel).
top_bar_kind	Top bar menu (menu).
lmenu_kind	Pulldown menu (menu).

Table 6-1 Container widgets

Widget Kind	Description
xcontainer_kind	Lower-level window (subpanel).
xscroller_kind	Scrollable lower-level window (scroller).

Table 6-1 Container widgets (continued)

Table 6-2 describes the kinds of primitive widgets.

Widget Kind	Description
xbutton_kind	Push button (command button, panel button, menu button, message button, and select button).
xswitch_kind	Two-state toggle (switch).
xchoice_kind	Multiple-state toggle (choice).
xtoggle_kind	Multiple-state toggle (toggle).
xcombo_kind	Multiple-state toggle (combo).
xfield_kind	For alphabetic/numeric input (field).
xslider_kind	For numeric input (slider).
xlist_kind	Multiple-entry selector (list).
xtext_kind	To display textual data (text).
xcanvas_kind	To display graphic data (canvas).
xlabel_kind	To display static text (label).
xseparator_kind	To separate other widgets (separator).

Table 6-2 Primitive widgets

Behavior

Behavior is defined as how the widget will respond to user actions. There are several types of widget behavior:

active Sensitive to keyboard/mouse input.

passive Insensitive to keyboard/mouse input.

monitored Having a value of certain type associated to it such that changes in the widget value, by code or as result of certain user action, can be monitored.

handled Can accept one or more handlers to respond to certain user actions.

entried Having an **sarray** of **lstring** as its entries and its value being the ordering of one of its entries.

All monitored widgets have a **ucap** view of simple type (**boolean**, **integer**, **real**, or **lstring**) to store its value and to monitor changes in its value, except fields whose **ucap** view is of type **numstring**.

There are many kinds of widgets, each having its own appearance and behavior.

Operations on any kind of widget usually work directly on its **mnode** view. However, there are some widget operations which work only on its panel view.

There are two types of operations working on **mnode** view:

general Work on all or more than one kinds of **mnode**s.

specialized Work on only a single kind of **mnode**s, names of such operations usually include name of the widget kind.

All operations on panel view work on all kind of **mnode**s.

Top Panel

Top panel is top-level container **mnode** whose existence is independent of other panels.

A top panel can be pushed, popped, or iconized independently of other top panels.

Each top panel must belong to some module and is identified by the name of its module together with its name.

Top panel can interact with WM though WM handlers. Currently, four kinds of WM handlers are defined:

"activate	Left mouse button is clicked inside panel the first time after cursor moves into it.
"move	Panel is moved interactively.
"resize	Panel is resized interactively.
"quit	Panel is to be closed using panel WM menu.

Named handlers defined for top panel:

"popup	Called right before the panel is seen on the screen.

A top panel, besides its own widgets, can include a menu bar at the top for pulldown menus. A top panel can include menus as its only children; such a top panel, called a **top bar**, shows only the menu bar for pulldown menus.

Item Panel

Item panel is top-level container **mnode** which is logically dependent on a top panel or another item panel, called its owner or parent.

An item panel is always displayed on top of its owner, cannot be iconized, and will be dismissed when its ancestor top panel is iconized or dismissed.

Each item panel must belong to some module and is identified by the name of its module together with its name.

An item panel can interact with WM though WM handlers. Currently, four kinds of WM handlers are defined:

"activate	Left mouse button is clicked inside panel the first time after cursor moves into it.
"move	Panel is moved interactively.
"resize	Panel is resized interactively.
"quit	Panel is to be closed using panel WM menu.

Named handlers defined for item panel:

"popup	Called right before the panel is seen on the screen.

An item panel can have built-in command buttons shown at the bottom of the panel, called footers, to be used as the action area for those panels whose widgets do not cause immediate actions.

Menu

Menu is a container **mnode** for menu items.

There are two kinds of menus:

menu bar	Always displayed at top of a top panel.
pulldown menu	Popped up when a menu button is activated.

A pulldown menu can include the following kinds of **mnode** as its children:

- Menu button
- Command button
- Panel button
- Switch
- Separator

Simple Widget Programming

Panels created using the *Visual SIL Window* are saved in the file system under

~/cim/gui/panels/<module>/<name_of_panel>.<version>

> **NOTE** Using the *Visual SIL Window* is described in Chapter 7, "Customizing the Menu Interface" in the *SilTools User's Manual*, available from SILMA, Division of Adept Technology, Inc.

The file **~/cim/builds/<versioned_area>/panels** lists the panels to be included in the given area. When a build is done, the panels indicated in the **panels** file are loaded in.

For example, in the **itest** area, there is a panel named **test_panel**. The **~/cim/builds/itest1/panels** file contains a line: **test_panel.5**. The file containing the panel is in **~/cim/gui/panels/itest/test_panel.5**.

This panel was saved under the name **test_panel** (5 is the version number).

A panel is represented in SIL by a value of type **mnode**.

> **NOTE** See "The mnode Class" on page 6-1 for more information on **mnode**s.

You can access all panels using pathname syntax in the following way:

```
<module_name>$<panel_name>
```

This is a SIL expression whose value is the given panel. For example, the test panel is

```
itest$test_panel
```

The components of a panel, such as containers and other widgets, can be selected by pathname as in this example:

Example 6.1

itest$test_panel["test_container]["test_toggle]

is the test panel component named **test_toggle** (a toggle widget) which resides inside a container.

The behavior of a panel is specified by giving SIL callbacks for its widgets. There are two kinds of callbacks: **handlers** and **monitors**.

Handlers

A widget, such as a button, which records an action has a handler. The handler is set with this procedure:

```
set_handler(mn:mnode;i:id);
```

The handler should take an **mnode** as input—it will be called with the **mnode** that generated the event.

Example 6.2

Suppose that

my_panel["my_button]

is a button. Then,

```
procedure announce_click(x:mnode);
begin
    writeln('Button ',name(x),' was clicked');
end;
set_handler(my_panel["my_button],"announce_click);
```

will cause

```
Button MY_BUTTON was clicked
```

to be printed when the button is pressed.

Monitors

Widgets, such as sliders and text fields, which record a value entered by the user, have a kind of callback called a **monitor**. A monitor is very close to a handler: it is a SIL procedure taking an **mnode** as input that is run whenever a new value is entered in a widget.

add_monitor(mn:mnode;h:id);
adds a monitor to **mn**.

Example 6.3

Suppose that

`my_panel["my_number_field]`

is a field which accepts real numbers, Then

```
procedure announce_number(x:mnode);
begin
     writeln('Number field ',name(x),' has value ',
               field_real_value(x)));
end;
add_monitor(my_panel["my_number_field], "announce_number);
```

will cause

```
Number field MY_NUMBER_FIELD has value 6.28
```

to be printed when the number 6.28 is entered into the field widget.

Optionally, filters may be added to a field such that only certain legal values may be entered. The **filter** function is called before the value is accepted by the widget and returns TRUE or FALSE indicating whether the value is legal. If the filter returns FALSE, the value will not be accepted and the field's monitors not called.

set_field_filter(mn:mnode;h:id);
adds a filter to **mn**.

You need to reset the field's value in case the filter rejects the new value, or else the illegal value will remain in the field's display. You can also notify the user that a illegal value was entered by displaying an information box.

Example 6.4

Continuing Example 6.3:

```
function filter_less_than_two(x:numstring) : boolean; var ok :
                                        boolean;
begin
      ok := TRUE;
      if(real_of(x) < 2.0) then
         begin
      init_field_val(my_panel["my_number_field],
                     field_real_value(my_panel["my_number_field]));
      info_dialog(list(make_prompt('Value must be >= 2'),
                     make_prompt('thank you.')));
      ok := FALSE;
      end;
filter_less_than_two := ok;
end;
set_field_filter(my_panel["my_number_field],
                   "filter_less_than_two);
```

displays

```
Value must be >= 2     thank you.
```

in a pop up box when the number 1.3 is entered into the field widget. The field will reset to show its previous value.

Each kind of widget has an accessing function that allows the current value to be read, as in this example:

Example 6.5

```
function slider_value(x: mnode): integer;
```

reads the current value of a slider.

The SIL code implementing handlers and monitors and also the code which hooks them to their widgets will typically appear in the same code module where the panel's code resides.

Footers

Footers behave like push buttons, executing an action when the button is clicked. However, footers are automatically laid out across the bottom of a panel, and cannot be manipulated like other visual elements. To associate an action with a footer command, use

set_footer_handler(pn : mnode; ft : id; hd : id);
This function adds a handler to the footer **ft** in panel **pn**.

Displaying Panels

For testing, it is often useful to be able to install a panel constructed by the *Visual SIL Window* without having to do a build. This can is done by using

```
load_panel(module_name: string; panel_name: string);
```

The panel may then be displayed by calling

```
put_up(mn: mnode);
```

The panel may be removed from the display by calling

```
bring_down(mn: mnode);
```

Advanced Widget Programming

This section describes how to program shape fields and graphics tools (**gtool**s). Shape fields and graphics tools (**gtool**s) are powerful interface elements, allowing graphical shape picking and general graphics operations in panels respectively. The Move Object panel is a good example of shape fields and **gtool**s in action. The shape field at the top of the panel picks the object to move, and **gtool** linked to a container performs the actual move function graphically.

Before using the information on shape selectors, selector widgets need to have been created using the *Visual SIL Window*. Graphics tools can only be created by programming.

NOTE Using the *Visual SIL Window* is described in Chapter 7, "Customizing the Menu Interface" in the *SilTools User's Manual*, available from SILMA, Division of Adept Technology, Inc.

Shape Fields and Graphics Tools

Shape Fields

Shape fields are widgets that enable shape picking inside panels. **gtool**s differ from shape fields in that they support more general interactive graphics operations.

There are two kinds of shape fields: **global_browser_kind** and **global_getob_kind**.

global_browser_kind

This is the kind for shape processors, which are "wired" to the middle mouse button (this is also called **speedup**). The selector widget "binds" a mouse button (always the middle button) whenever the selector is active. That is, when this selector is up and active, selecting an object in either the

Quick Pick Window or *Graphics Window* automatically changes the selector's value—there is no need for the user to click the selector.

global_getob_kind

This is the kind for shape selectors, which borrows the mouse temporarily. Clicking on the selector widget puts the interface into **getob** mode. In **getob** mode, the user must select a shape or cancel. The left mouse button is always used for selecting.

NOTE **global_getob_kind** should not to be confused with the **shape_selector** object mentioned below.

Both shape processors and shape selectors have an option that enables the user to select more than one object, if desired. If this option has been added to the shape field, the widget looks different:

Multi-Pick Shape Processor

Multi-Pick Shape Selector

Figure 6-1 Multiple-object shape fields

NOTE "Groups" on page 6-24 provides additional commands used in multiple-object shape selection.

The value of a shape field can either be a shape or a string. The function **shape_field_has_shape** is used to test for which one it is. Two accessor functions are used to get the appropriate value: **shape_field_shape_value** for a shape and **shape_field_string_value** for a string. If more than one shape was selected, the group shape is returned.

The **shape_selector** class provides a way of indicating a shape by abstracting the common functionality of the shape fields. As a special case, a shape field is hooked up slightly differently than other widgets.

To run an action whenever a shape (or shapes) is selected, set the shape selector's **iexecute** method. **iexecute** method, if any, is called when the value of the shape field is changed. Note that the execute method, if set, should take an **mnode** as argument.

To add a filter to the shape field, set the shape selector's **ifilter** method. **ifilter** method, if any, determines which shapes are legal selections. If no filter method is defined, a default filter is used which screens out shapes which are internal parts of a compacted model.

If a value for a shape field is picked in the *Graphics Window*, the value returned is the nearest ancestor which satisfies the filter. Again, if no filter is specified, the tree is climbed to the nearest ancestor which is not a component of a compacted model.

A shape field is created by first creating a selector widget using the *Visual SIL Window*, and then applying either **global_getob_kind** or **global_browser_kind** to add the shape selection functionality. In each case, a **shape_selector** view is spliced onto the selected **mnode**.

To create a shape field, use

```
mk_shape_field(selector_widget: mnode, knd: integer,
                    bt: button): mnode;
left_button
middle_button
```

To add highlighting such that the shape field's value is shown graphically, use

```
function mk_hl_shape_field(selector_widget: mnode):
                                    hl_shape_selector;
```

When a shape is deleted from the World, a shape field which previously had the shape as current value may substitute it with another.

To add re-initialization if shape is deleted, use

```
function mk_initializing_shape_field(selector_widget: mnode,
                                     a_closure: closure (ob)):
                                     initializing_shape_selector;
```

The **initializing_shape_selector** has a **reinit** closure, which when called should return the new value:

```
initializing_shape_selector.reinit: shape closure(ob);
```

To add the multiple-selection option, use

```
function set_supports_multi(selector_widget: mnode,
                                     is_multi: boolean);
```

Graphics Tools

Graphics tools (**gtool**s) are entities which support general graphics operations and can respond to mouse activity within the *Graphics Window*. **gtool**s assign meaning to a click or drag in the *Graphics Window*, but not the *Quick Pick Window*. By convention, **gtool**s are always bound to the left mouse button. While there is no widget associated with the **gtool**, they can easily be added to a panel, and hooked up much in the same way as shape selectors.

There are three kinds of **gtool**s: shape-click tools, group tools and general tools.

Shape-Click Tools

Tools whose action is determined only by the position of the mouse when the button is released. Such a tool will fill in the **shape_of** field with the shape under the mouse. A shape-click tool is created with the constructor

```
function mk_shape_click_gtool(name: id): gtool;
```

The operation to access a shape-click tool is

```
function is_shape_click_gtool(gt: gtool): boolean;
```

Group Tools

Tools that act on a group defined by dragging. Here, the tool is activated when the mouse is released and the **group_of** is filled in with the shapes within the 2D box indicated by the drag. A group tool is created with the constructor

```
function mk_group_gtool(name: id): gtool;
```

The operation to access a group tool is

```
function is_group_gtool(gt: gtool): boolean;
```

General Tools

Tools that do all their own computations (that can act in whatever manner the programmer sees fit when the mouse is pressed, dragged and released). A general tool is created with the constructor

```
function mk_general_gtool(name: id): gtool;
```

The operation to access a general tool is

```
function is_general_gtool(gt: gtool): boolean;
```

Making Shape Fields and Graphics Tools Work

A tool set attachment must be added to each panel which has a shape field or **gtool** wired to the mouse. These shape fields and **gtool**s are generally called **tool**s.

Tool Sets and Tool Bodies

Only one tool set may be active at a time and tool sets are always associated with panels—clicking the mouse button with the cursor in the panel activates the panel's tool set and changes the border color. Tools are active only when their tool set is active. In the simplest case, a tool set can hold two tools which bind both mouse buttons. Because a panel may have many tools which need to be wired and there is only one mouse, tool bodies support switching of

tools within a tool set. **Tool bodies** are holders for one or more shape selectors or **gtool**s, which bind one or both of the mouse buttons. Tool bodies are always associated with container widgets, often overlaid such that only one is visible at a time. In a typical scenario, a panel consists of a switch, a set of operations, where selecting an operation causes a particular container to appear and its tool body to be activated. Each tool set has, at most, one current tool body, which will be activated when the tool set is, and the tool set can bind one or both of the mouse buttons as default, if the current tool body does not.

Example 6.6

The **move** tool set includes a **shape_field** which determines which shape will be moved. The tool set has many tool bodies, one of which is the XY **tool_body**. The tool set in this case binds the middle button, and the XY body binds the left button. In particular, clicking the middle mouse button in the *Graphics Window* or the *Quick Pick Window* updates **shape_field** field to that shape. Clicking (or dragging) the left mouse button causes the current **shape_field** shape to jump (or drag) to the location on the XY plane over which the mouse is clicked (or held down).

In general, browser shape fields should be used only in cases where an operation is primarily graphical in nature, meaning that the mouse will remain in the graphics views for the duration of the operation. Because a tool set takes over the current mouse binding when active (even if it does not contain tools which bind the mouse buttons), a panel which does not have browser shape fields or **gtool**s does not need, nor should have, a tool set.

To turn a panel into a tool set, use

```
mk_tool_set(mn: mnode)
```

To turn a container into a tool body, use

```
mk_tool_body(mn: mnode, ts: tool_set)
```

Binding a Mouse Button

The **bind_button** command is used to add a tool to either a tool body or the tool set as the default tool.

```
function bind_button(mn: mnode;
                     bt: integer;
                     shs shape_selector);
```

where **bt** is always the middle_button (2).

```
function bind_button(mn: mnode; gt: gtool);
```

Controlling which Tools are Active

This procedure activates the given body; that is, this body will replace the current body (if any):

```
set_body(ts: tool_set, tb: tool_body)
```

Tool Set and Tool Body Methods

Two methods are called when the tool set and tool body are activated and deactivated:

at_activate called when the tool set or tool body is activated.

at_deactivate called when the tool set or tool body is deactivated.

Specifying Tool Actions for Graphics Tools

The action taken by each kind of tool is specified by defining its execute method.

For a shape-click tool, the execute method will be run when the mouse button is released.

When the execute method is run, the following occurs:

- The **pos** field is filled in with the screen coordinates where the click occurred.
- The previous **pos** is copied into **last_pos**.

- The **shape_of** field is filled in with the shape selected by the click.

The predicate method of the tool determines which shapes are available for selection by a shape-click tool.

A group tool is similar to a shape-click tool, but will show a box on the screen when the mouse is dragged, and fills in the **group_of** field when the mouse is released with the group of shapes in the box. It will also set the **shape_of** field to the group shape representing the group.

In the case of a general tool, the execute method is run whenever the mouse button is pressed, released, or moved while pressed. **pos** and **last_pos**, and **action** fields are filled in. The values of the **action** field are

buttonpress

buttonrelease

motionnotify

leavenotify The mouse cursor was moved out of the *Graphics Window* while the mouse button remained pressed.

enternotify The mouse cursor returned to the *Graphics Window* while the mouse button remained pressed.

Other gtool Methods

Two methods are called when a **gtool** is activated and deactivated:

at_activate called when the **gtool** is activated.

at_deactivate called when the **gtool** is deactivated.

Obtaining Additional Information

If you would like more information about the results of using the shape field or **gtool**, you can use this function after the pick is made:

get_pick_extended_info(): pick_extended_info;
Detailed information on the result of the pick will be returned.

The structure of the **pick_extended_info lrecord** includes the following fields:

Variable	Type	Meaning
something_selected	**boolean**	Was anything selected?
selected_object	**object**	The selected object.
point_was_selected	**boolean**	Was a vertex selected?
selected_vertex	**point**	Coordinates of the selected point.
seg_was_selected	**boolean**	Was a line segment selected?
selected_seg	**seg**	The selected line segment.
facet_was_selected	**boolean**	Was a facet selected?
selected_facet_point	**point**	The point selected on the facet.
selected_facet_normal	**dir3dr**	The normal to the selected facet.
selected_screen_point	**pnt2di**	The screen coordinates of the mouse selection.

Table 6-3 Graphical-picking global variables

Widget Toggles

A common use of the toggle is to switch between distinct but related operations. To conserve panel space, multiple container widgets are overlaid beneath the toggle. Adding a monitor to the toggle enables the container to be initialized when it's displayed. Selecting an operation with the toggle displays a specific container that has all widgets needed to perform the operation. The widget toggle associated with a list of container widgets automatically displays the appropriate container.

widget_toggle is a subclass of **toggle_mnode**, associating a container widget with each toggle item, such that selecting a toggle item causes the associated container to be displayed and the remaining containers to be hidden. If these containers are in the **tool_body** class, selecting the toggle item will activate the associated **tool_body**.

```
mk_widget_toggle(mn: toggle_mnode, cnts: list of mnode);
```

To install new container widgets, use this procedure:

```
install_new_widget_toggle_entries(mn: mnode,
                                  cnts: list of mnode);
```

To add container widgets, use this procedure:

```
add_widget_toggle_entry(mn: mnode, cnts: mnode);
add_widget_toggle_entry(mn: mnode, cnts: mnode,
                        index: integer);
```

To remove container widgets, use this procedure:

```
remove_widget_toggle_entry(mn: mnode, cnts: mnode);
remove_widget_toggle_entry(mn: mnode, index: integer);
```

The common panel organization has a toggle widget at top, under which multiple container widgets are stacked on top of each other, with only one being visible at a time.

Examples

Example 6.7 illustrates simple shape picking and adding a shape field to a panel.

Example 6.7

```
panel = itest$test1
selector widget = sw

init_test1()
{
    mk_shape_field(sw, global_getob_kind, left_button);
    mk_hl_shape_field(sw);
    set_method(sw as_view
                shape_selector, "ifilter, "monitor_filter,
                list(mnode, shape));
        {monitor_filter determines whether shape is valid. Returns
        TRUE/FALSE}

    set_method(sw as_view
                shape_selector, "iexecute, "execute_function,
                list(mnode));
        {execute_function looks to shape_field_value(mnode),
        which is an ob, and sees if the value is a string or shape, then
        performs some action}
}
```

Example 6.8 illustrates speedup shape picking and adding a shape speedup field.

Example 6.8

```
panel = itest$test2
selector widget = sw

init_test2()
{
    test2_tool_set:= mk_tool_set(panel);
    mk_shape_field(sw as_view field_button,
                    global_browser_kind, middle_button);
    mk_hl_shape_field(sw);
    set_method(sw as_view
                shape_selector, "ifilter, "monitor_filter,
                list(mnode, shape));
      {monitor_filter determines whether shape is valid. Returns
      TRUE/FALSE}
    set_method(sw as_view
                shape_selector, "iexecute, "execute_function,
                list(mnode));
      {execute_function looks to shape_field_value(mnode),
      which is an ob, and sees if the value is a string or shape, then
      performs some action}
    bind_button(panel,middle_button,sw as_view
                shape_selector);
}
```

Graphical Picking

The preceding section explained how to add graphics picking to a panel. This section explains how to enable the user to perform a graphics pick without using a panel that has been displayed from the menus. This facility is included primarily to support older (pre-Release V) versions of SILMA software.

To prompt the user to select an object from the *Graphics Window* or *Quick Pick Window*, use the function

```
get_graphics_pick(message: string): boolean;
```

When this function is executed, a pop up box is displayed. The pop up box instructs the user to pick an object by clicking on one in the *Graphics Window* or the *Quick Pick Window*. After the pick is made, you can obtain information about the graphics pick by using the function described in "Obtaining Additional Information" on page 6-19.

The **get_graphics_pick** function returns TRUE if something is selected, and FALSE if the user aborts by clicking the *Cancel* selection in the pop up box.

A more powerful version of the command is

```
get_graphics_pick(message: string; screening_function: id):
                                    boolean;
```

This command applies the **screening_function** to each object that a user selects, and returns only when this screening function returns true. Example 6.9 requires the user to pick until a frame or the teacher is selected (or the selection is aborted).

Example 6.9

```
var pick: boolean;;

function is_frame_or_teacher(x: object): boolean;
      begin
         is_frame_or_teacher := is_frame(x) or is_teacher(x);
      end;

pick := get_graphics_pick('Pick a frame.',
                                    "is_frame_or_teacher);
```

Groups

The grouping mechanism provides a way to perform the same operations on more than one shape at a time. A group is treated by the user interface as a shape, even though its members are not a part of the World shape tree. There are several ways to create a group; for example, you can create one by clicking and dragging a rubber band object in the *Graphics Window* or using the Create/Edit Group panel.

If you are planning on using multiple-object shape selectors, you should first familiarize yourself with the information in “Shape Fields and Graphics Tools” on page 6-11 on how to enable a shape field to select groups of shapes, then use the commands in this section.

This command determines if an object is a group shape:

```
is_group(object:model):boolean;
```

This command returns the members of a group, treated as a list of pathnames.

```
value(gr: group):list of pathname;
```

wlkup(pathname) can be called on each element to get the shape.

A group can be created by calling a short set of API functions.

This command constructs a group that the user can select in the *Quick Pick Window*, and edit from the Create/Edit Group panel:

```
mk_group(name:id; members:list of pathname):group;
```

This command constructs a group that will *not* appear to the user in the user interface:

```
mk_tmp_group(name:id;members;list of pathname):group;
```

This command must be called after **mk_group** or **mk_tmp_group**:

```
add_group(gr:group);
```

This command deletes a group:

```
delete_group(gr:group);
```

File Browsing

The file browser is a panel which enables the user to browse the file system and select a file. To activate the file browser, use the function:

procedure ib_pop_file(mn: mnode; ttl: string; nm: string; sd: string; ext: string; fn: id; flgs: integer);

where

mn is an optional argument that specifies which panel the file browser will appear next to on the screen, and this can be nil.

ttl is a title shown at the top of the file browser.

nm is a label for the kind of entity the file will select (e.g., cell, movie).

sd is a subdirectory to search when the current directory is a library.

ext is a file extension to search for.

fn is the name of a function to call once a selection has been made. This function will be passed two strings: the first specifies the name of the file, and the second specifies the full pathname.

flgs are flags which can set various options:

ib_file_save An additional text field prompts the user to enter a new filename.

ib_file_no_save_list The file browser will not show the file contents of the current directory.

ib_file_no_lib The user will not be given the option of changing directory.

ib_file_save_confirm Prompts the user to confirm his selection if the file already exists. This is used only when **ib_file_save** is set.

Example 6.10

This example illustrates how to save data collected from a simulation:

```
procedure save_my_data(filename: string; pathname: string);
begin
     { This is where I save it }
end;

ib_pop_file(mymodule$mypanel,'Save Simulation Data',
                'simulation data','data','sim_data', "save_my_data,
                ib_file_save + ib_file_save_confirm);
```

Requestor and Message Panels

Pop Up Boxes

Pop up boxes are modal panels which prevent the user from taking further action until the pop up box is dismissed. Pop up boxes can display messages, present choices, and request information.

make_prompt(string): intf_prompt;
info_dialog(list of intf_prompt);

Display a message for the user to acknowledge.

make_prompt(message: string):intf_prompt;

Constructs an **intf_prompt**.

info_dialog(message: list of intf_prompt);

Displays a message in a pop up box that the user *must* acknowledge. Program execution is halted until the user clicks *OK*.

sure(list of intf_prompt): boolean;

Presents the user with a yes or no choice.

sure(message: list of intf_prompt):boolean;
sure():boolean;

Displays a message in a pop up box, and presents the user with an option of selecting *OK* or *Cancel.* Program execution is halted until a selection is made. The function returns when either selection is chosen.

NOTE This is also called a confirmation requestor.

get_a_string(list of intf_prompt): anno_string;

Requests a string from the user. The user is given the option of cancelling the selection. **anno_string** ia defined in the following section. Additional similar functions are also described in the following section.

NOTE Additional functions are documented in the *SilTools Command Reference*, available from SILMA, Division of Adept Technology, Inc.

Annotated Types

Annotated types are useful when a function can return a value or "no value", such as the case of **get_a_string** where a user can either enter a string or cancel.

Annotated types include **anno_string**, **anno_boolean**, **anno_integer**, and **anno_real**. These types are defined as records that have two fields:

anno A boolean that records whether or not a value was entered.

val A value (if one was entered).

The following functions return an annotated value:

get_a_real(message:list of intf_prompt):anno_real;
get_a_real():anno_real;
get_an_integer(message:list of intf_prompt):anno_integer;
get_an_integer():anno_integer;
get_a_boole_tf(message:list of intf_prompt):anno_boole;
get_a_boole_tf():anno_boole;
get_a_boole_yn(message:list of intf_prompt):anno_boole;
get_a_boole_yn():anno_boole;
get_a_boole(message:list of intf_prompt):anno_boole;
get_a_boole():anno_boole;
get_a_string(message:list of intf_prompt):anno_string;
get_a_string():anno_string;

Pops up a message in a pop up box prompting the user to input a value.

Program execution is halted until the user enters the value or cancels the selection.

Online Help

A panel may have a help file available online. Pressing the <HELP> key while the cursor is on the panel will display the help information. To set help, use

set_help(mn: mnode; file: string);

where **file** is a relative pathname from **`~/cim/gui/help`**.

The help file is an ASCII text file. Formatting should be kept simple and every paragraph placed in a single line. Since the help text will wrap around to the next line automatically, you do not need to be concerned about the size of the *Help Window*.

Installing Panels

Adding a Panel into the Pulldown Menus

A panel may be added to a product by editing the top bar panel for that product. This can be accomplished using the *Visual SIL Window* by loading and editing in the current top bar panel then saving the revised panel into a new file and updating the build area where the top bar panel resides.

Adding a Panel into the Quick Access

A panel may be added into the Quick Access using the *Visual SIL Window*, or during initialization by calling

```
create_rolodex_mnode_nm(mn:mnode);
```

NOTE If a panel will be used as a tool set, it should first be made into a **tool_set**, before adding it to the Quick Access.

Adding a Panel into the Tool Bar

A panel may be added into the tool bar using the *Visual SIL Window*, or during initialization by first calling

```
create_toolbar_mnode(mn: mnode; bid : id; pict : string);
```

where **bid** is an **id** given to the new button to be created and added into the tool bar and **pict** is the relative pathname of the icon **pixmap**. All pixmaps and bitmaps should reside under the **`~/cim/gui/icons`** directory.

To make the panel appear in the tool bar, call

```
add_panel_to_toolbar(tm : toolbar_mnode);
```

Example 6.11

```
aaa==create_toolbar_mnode(itest$test1,"test1,'test_icon');
```
sets **`itest$test1`**'s icon to **`~/cim/gui/icons/test_icon`**.
```
add_panel_to_toolbar(itest$test1 to_view toolbar_mnode);
```

Making a Panel Operational

All panels belong to a particular build area, so code associated with making a panel work should be placed in that same build area. The first step in making a panel operational is to "hook up" a panel by adding monitors and handlers, setting methods, and initializing the state of the widgets. This is done in the initialize method of the panel, which can be set using the *Visual SIL Window* or calling **set_method** in-line the SIL file.

Example 6.12

```
 procedure init_test_panel(mn: mnode);
begin
      add_monitor(mn["toggle],"test_toggle_monitor);
      ...
end;
set_method(itest$test_panel, "initialize, "init_test_panel,
                        list(mnode));
```

The next step is to optionally set the **at_pop** method of the panel. Setting the **at_pop** method both initializes the panel for use the first time and every time it is brought up. The **at_dismiss** method may also be set and will be called each time the panel is brought down.

Customizing the Application

The Menu Bar

The menu bar is specified in each product's **`top_init.sil`** file. Set the **`top_bar`** variable to be the menu's panel.

Customizing the Logo

The **logo** is a small panel which contains a button with the product's logo. When the button is pressed, an action may take place.

To change the product's logo, use

```
set_label_icon(ikern$logo["command]; pixmap_file: string);
```

By default, a small panel pops up with text inside. To change this text, use

```
install_new_list_entries(ikern$logo_info["list],
                         entries: sarray_of(lstring));
```

To change the action that occurs when the button is pressed, use

```
set_handler(ikern$logo["command],id);
```

REMINDER All icons should be placed under the **`cim/gui/icons`** directory.

Customizing the Layout

A product may save the location and size of certain panels to be restored each time the product is started. To create a new layout, arrange the panels inside the product then call

```
save_r_current_layout();
```

This must be done for every screen geometry on which this product will be run.

To add more information to the settings, i.e. save the position of new panels a new layout constructor must be written. The **layout** constructor must be of the type **function(setting);**.

Taking no arguments, this function must return a setting object. The function to create a new setting is

std_mk_layout_settings(nm : id, ls : list of setting);

The functions to create a specific setting include the following:

mk_panel_geom_setting(nm : id; panel :id; pos : id; xt : id);

where **nm** is the name of the setting, **panel** is the name of the panel, **pos** and **xt** are the names of the global variables which optionally may be set when the layout is restored. If no such global variables, exist nil may be substituted.

mk_panel_pos_setting(nm : id; panel :id; pos : id);
Similar to **mk_panel_geom_setting** except only the **pos** and not the extent of the panel is saved.

mk_global_var_setting(nm : id);

where **nm** is the name of a global SIL variable. The value of this variable will be saved and restored.

Example 6.13

```
function mk_test_layout_settings():setting;
begin
     mk_test_layout_settings :=
                    std_mk_layout_settings("test_layout, list(
                    mk_panel_geom_setting("test1_geom,
                    "itest$test1,nil,nil),
                    mk_panel_geom_setting("test2_geom,
                    "itest$test2, "test2_pos, "test2_xt),
                    mk_panel_pos_setting("test3_pos, "itest$test3,
                    "test3_pos),
                    mk_global_var_setting("test_var")));
end;
the_layout_constructor := "mk_test_layout_settings;
```

To relocate the Quick Access, you need to add the following code to **`top_init.sil`**:

```
base_rolodex.top_init := [newx, newy] as pnt2dr;
            base_rolodex.top_loc := [newx, newy+8] as pnt2dr;
            moveto(ikern$rolodex,base_rolodex.top_init);
```

where **newx** and **newy** is the new location of the Quick Access.

Customizing the Start Up Screen

The start up screen is displayed while the menus are initializing. The start up screen can be configured in the file **`cim/templates/<product>/startup.msg`**.

The format is as follows:

`FONT <STRING>`	Sets the font. Example: **`FONT -adobe-helvetica-bold-r-normal--12-120-75-75-p-70-iso8859-1}`**
`TEXTCOLOR <STRING>`	{Sets the text color. Example: **`TEXTCOLOR blue`**}

`FOREGROUND <STRING>`	{Sets the foreground color for all monochrome bitmaps}
`BACKGROUND <STRING>`	{Sets the background color for all monochrome bitmaps}
`TEXT LEFT <X-COORD> <Y-COORD> <STRING>`	{Writes text left justified starting at X, Y. Example: **`TEXT LEFT -200,-100 This is a test product`**}
`TEXT RIGHT <X-COORD> <Y-COORD> <STRING>`	{Writes text right justified ending at X, Y}
`TEXT CENTER <X1-COORD> <X2-COORD> <Y-COORD> <STRING>`	{Writes text centered between X1 and X2 at Y}
`IMAGE PLACE <X-COORD> <Y-COORD> <LOGO FILE>`	{Shows image as location X, Y. Example: **`IMAGE PLACE START START test_logo`**}
`IMAGE CENTER <X1-COORD> <Y1-COORD> <X2-COORD> <Y2-COORD> <LOGO FILE>`	{Shows image centered between X1, Y1 and X2, Y2}
`COORD: START, END`	{The edge of the screen}
`-number`	{Offset from the lower right corner}
`number`	{Offset from the upper left corner}
`STRING`	{$ = (R) @ = (C) % = TM}
`LOGO FILE`	{A bitmap or pixmap from the **`cim/gui/icons/logo directory`**}

Chapter 7

Vision

SIL functions can be installed inside user programs to perform the same actions as selecting the Vision panel selections. Using SIL functions in this way enables users to create programs for simulating vision or even choreographing their simulations. In the case of choreography, the cameras can be hidden so that the camera ring is not visible when enabling vision.

Additional SIL functionality is provided for “auto-level”. This function automatically keeps the camera horizontal (views never become upside-down or sideways)—the camera will always have a horizontal horizon.

This procedure installs a new camera into the workcell:

procedure install_cam();

The camera is installed, automatically named and painted. Cameras are painted a **<color>** and automatically named **cam_<color>**.

This procedure sets the target for a specified camera:

procedure target(c,targ: string);

where **c** is the camera and **targ** is the target.

This function returns the target for a specified camera:

function target(c: string):string;

where **c** is the camera.

This procedure sets the tracking status of a specified camera:

procedure tracking(c:string; op:boole);

where

c is the camera.

op = **true** switches tracking on and **op** = **false** switches tracking off.

This function returns the tracking status of a specified camera:

function tracking(c:string):boole;

where

c is the camera.

This function sets the focal length for a camera:

procedure focal(c:string; fl:real);

where

c is the camera.

fl is the focal length.

This function returns the focal length of a camera:

function focal(c:string):real;

where **c** is the camera.

This procedure sets the auto-level status of a specified camera:

procedure autolevel(c:string; op:boole);

where

c is the camera.

op = **true** switches auto-level on and **op** = **false** switches auto-level off (default).

This function returns the auto-level status of a specified camera:

function autolevel(c:string):boole;

where **c** is the camera.

This procedure activates vision in the current view:

procedure vision(c:string; op:boole);

where

c is the camera that will have vision enabled for it.

op = **true** switches vision on and **op** = **false** switches vision off.

This function provides information about the tracking status:

function is_tracking():anno_shape;

Returns if the camera in the current window is tracking, and what the target is (provided vision is switched on in the current view).

Returns **`[false, empty_shape]`** if vision is switched off.

This function provides information about where the lens is located:

function is_mounted():anno_shape;

Returns TRUE (provided vision is switched on). The shape that is returned is the object the lens is affixed to.

To find out which “camera” has vision switched on, use

```
label(parent(is_mounted().val));
```

Chapter 8

Modeling Using SIL Commands

Creating models using the menus and panels is usually the most efficient way to create models. You can also, however, create models using the SIL language. The first part of this chapter describes how to create models using SIL commands. The last part of this chapter provides examples of models.

The model Data Type

All SilTools models, both rigid and structured, are represented internally with the same data type: **model**. The **model** data type is a data structure with fields for the following:

1. The name of the model. This name is used during a simulation to refer to the model and its components. Names are always given as strings.
2. Its kind (rigid or structured).
3. The model body.
4. The color of the body.
5. Pointers to the model's submodels (if any).

Modeling Constructors

Because SilTools models are represented by their boundaries (which are in turn limited to vertices, edges, and facets), you will need only a few basic constructors to build even the most complex models. For convenience, you may build more sophisticated constructors out of these basic ones. SilTools provides some of these more sophisticated constructors—you can create the others using the following examples as guides.

The World coordinate frame is the base coordinate system used by all the modeling constructors. For this reason, all geometric values specified in the constructors are absolute values. Most constructors

return models centered on the origin of the World coordinate frame. They may be transformed to new locations with the **moveto** and **moveby** commands.

Operator	Resulting Shape
mk_point(<xc>,<yc>,<zc>)	Cartesian point

Curves

Operator	Resulting Shape
mk_rctcurve (pts : darray of pnt3dr)	rctcurve
mk_rctcurve (pts : darray of pnt3dr; n : integer)	rctcurve
n use **[0.. n]** points as input	
mk_rctcurve (p,q : pnt3dr)	rctcurve
mk_circle (r : real)	circle
centered at origin	
mk_circle (radius : real; p : pnt3dr)	circle
p center	
mk_circle (radius : real; f : frame)	circle
f circle defined w.r.t the frame	
arc (r,a : real; res : integer)	circle
r radius	
a angle in degrees **[0..360.0]**	
res resolution	
arc (r,a : real)	circle
r radius	
a angle in degrees **[0..360.0]**	
arc (r : real)	circle
r radius	

Conics

a-x coefficients, b-y coefficients

Operator	Resulting Shape
mk_ellipse (a,b: real)	ellipse
mk_parabola (a: real)	parabola
mk_hyperbola (a,b : real)	hyperbola

Operator		Resulting Shape
mk_rbspline (knts,wghts : darray of real; cpts: darray of pnt3dr)		rbspline
knts	knots	
wghts	rational part of the point called “weights”	
cpts	control points	
mk_rbspline (knts : darray of real; cpts : darray of pnt3dr)		rbspline
knts	knots	
wghts	all weights equal to 1.0	
cpts	control points	

Operator		Resulting Shape
mk_pcurvelist(pcs : list of pcurve)		pcurvelist
mk_pcurve (p : pnt3dr)		pcurve
p	point	
mk_pcurve (p : seg3dr)		pcurve
p	line segment	

Surfaces

Cap

angle 0 to 360 degrees creates partial cap

The edge of a partial cap starts at x = <**radius**>, y = 0, sweeps counter clockwise <**angle**> degrees around the Z axis, and has an additional edge to close the polygon

resolution number of facets in cap (if omitted, **c_circ_res** is used)

Operator	Resulting Shape
mk_cap(<radius>[,<angle>]);	circular polygon
mk_cap(<radius>[,<angle>,<resolution>]);	circular polygon

Facet

The first three points establish the plane of the facet, and all points specified subsequent to them must lie in that plane. Order the points in the counterclockwise direction looking toward the facet from its outside. This establishes the direction of the facet's normal.

Operator	Resulting Shape
facet(list(<point1>,<point2>,<point3> [,...,<pointn>]));	convex planar polygon
facet(array(<point1>,,<point2>,<point3> [,...,<pointn>]));	convex planar polygon

Plane Surface

n normal

d distance to origin

sz extents

pl plane structure

Operator	Resulting Shape
mk_plsurf (n : dir3dr; d,sz : real)	plsurf
mk_plsurf (n : dir3dr; d : real)	plsurf
mk_plsurf (pl : plane)	plsurf

Grid Surface

g point grid

ng normal grid

Operator	Resulting Shape
mk_gsurface (g,ng : grid) (makes grid gsurface)	gsurface
mk_gsurface (g : grid) (makes grid gsurface for which normals are calculated automatically)	gsurface
psurf_to_gsurf (z : psurface) (generates discrete grid surface out of psurface)	gsurface

crvs1,crvs2 first, and second curve list

Operator	Resulting Shape
mk_rsurf (crvs1,crvs2 : list of pcurve)	rsurf

Be sure that pcurves are oriented correctly to avoid twisted ruled surfaces.

Surface of Revolution

crvs	generatrix curves
theta	angle revolution in rad
ax	axis of revolution

Operator	Resulting Shape
mk_rvsurf (crvs: list of pcurve; theta: real)	rvsurf
mk_rvsurf (crvs : list of pcurve)	rvsurf
mk_rvsurf (ax: seg3dr; crvs: list of pcurve; theta: real)	rvsurf
mk_rvsurf (ax : seg3dr; crvs : list of pcurve)	rvsurf

Tube as rvsurf

r	radius of tube
a	angle revolution in degrees (0 to 360)
h	height of tube
ur	resolution in circular direction (if omitted, **c_circ_res** is used)

Operator		Resulting Shape
tube	**(r,a,h: real; ur: integer)**	rvsurf
tube	**(r,a,h : real)**	rvsurf
tube	**(r,h: real)**	rvsurf

Funnel as rvsurf

r1,r2 first, and second radii of funnel

a1 angle revolution in rad

h height of tube

ur resolution in circular direction

Operator	Resulting Shape
funnel (r1,r2,a1,h : real; ur : integer)	rvsurf
funnel (r1,r2,a1,h : real)	rvsurf
funnel (r1,r2,h : real)	rvsurf

Tabulated Cylinder

endpt endpoint of generatrix

base directrix

Operator	Resulting Shape
mk_tcsurf (endpt: pnt3dr; base: list of pcurve)	tcsurf

Rational B-Spline Surface

knts1,knts2 u, v knots

cpts control points

wghts rational part of control points (weights)

Operator	Resulting Shape
mk_rbsurf (knts1,knts2,wghts: darray of real; cpts: darray of pnt3dr)	rbsurf
mk_rbsurf (knts1,knts2 : darray of real; cpts : darray of pnt3dr)	rbsurf

d1,d2	degrees in the u, v directions
fno	is a “formno” gives a simple description of what type of surface this really is, such as cylinder, sphere, etc.
coefs	coefficients of spline surf

Operator	Resulting Shape
mk_bsurf (fno,d1,d2: integer; knts1,knts2: darray of real; coefs: darray of pnt3dr)	rbsurf
mk_bsurf (d1,d2: integer; knts1,knts2 : darray of real; coefs: darray of pnt3dr	rbsurf

Coons Surface

sg1,sg2,sg3,sg4	line segment boundaries
pc1,pc2,pc3,pc4	pcurve boundaries
k	specifies the type: 0 for linear and 1 for cubic

Operator	Resulting Shape
mk_cnsurf (sg1,sg2,sg3,sg4: seg3dr; k: integer)	cnsurf
mk_cnsurf (pc1,pc2,pc3,pc4 : pcurve; k : integer)	cnsurf

The next variants for surfaces ensure that if any rectilinear curve is revolved about an axis or if any cylinder is built on a rectilinear curve, the subdivision that is generated will respect the vertices of the curve and not “round” them. Note that a **shape** is returned and not one of the surface types. The subshapes of this shape are the rectilinear (dsurface) and/or smooth (psurface) pieces of the shape. The variables **with_top** and **with_bottom** give the resultant shape a top or bottom, respectively. Note that the axis of rotation is along the Z-axis of the World coordinate system.

Operator	Resulting Shape
mk_rvsurf_shape (pc: pcurve; theta: real; with_bottom,with_top: boolean)	shape
mk_rvsurf_shape (pc: pcurve; theta: real)	shape
mk_rvsurf_shape (pc: pcurve)	shape
mk_rvsurf_shape (pcs : list of pcurve; theta : real; with_bottom,with_top : boolean)	shape
mk_rvsurf_shape (pcs : list of pcurve; theta : real)	shape
mk_rvsurf_shape (pcs : list of pcurve)	shape
mk_rvsurf_shape (ax : seg3dr; pcs : list of pcurve; theta : real; with_bottom, with_top: boolean)	shape
mk_rvsurf_shape (ax: seg3dr; pcs: list of pcurve; theta: real)	shape
mk_rvsurf_shape (ax :seg3dr; pcs : list of pcurve; with_bottom,with_top: boolean)	shape
mk_rvsurf_shape (ax: seg3dr; pcs: list of pcurve)	shape

Geometric Constructors

Conic Constructors

Let **z** be of type **conic2dr** (structure has general conic coefficients).

Let **tp** be an integer from {**hyperb_type,elips_type,parab_type**}.

NOTE	The next **mk_ellipse** and **mk_hyperbola** function below use type **conic_data = tuple_of(frame,real,real,integer).**

Operator	Resulting Shape
mk_ellipse(z,tp)	ellipse
mk_ellipse(z)	ellipse
mk_hyperbola(z,tp)	hyperbola
mk_hyperbola(z)	hyperbola
mk_parabola(z,tp)	parabola
mk_parabola(z)	parabola

Operator	Resulting Shape
mk_circular_arc (center,begpt,endpt: pnt2dr; zt: real)	circle
mk_circular_arc (center,begpt,endpt : pnt2dr)	circle

Bezier Curve Constructor

We string together Bezier curves defined by four successive points. If necessary, some points at the end are duplicated.

Operator	Resulting Shape
mk_pspline (p0,p1,p2,p3: pnt3dr)	pspline
p0 - p3 are the control points of the Bezier curve	
mk_psplines (pts: darray of pnt3dr)	pspline

Similar to **mk_psplines**, except here the resulting curve has continuous tangent vectors.

Operator	Resulting Shape
mk_pspline (pts : darray of pnt3dr; n : integer)	pspline
mk_pspline (pts : darray of pnt3dr)	pspline

Bezier Patch Constructor

Operator	Resulting Shape
mk_psurf (cpts: darray of pnt3dr)	psurf

cpts [0..15] is an array of control points for the Bezier patch.

g(u,v) = [1 u u*u u*u*u] B S Bt [1 v v*v v*v*v]t

Conic Surface Constructors

Operator	Resulting Shape
ellipsoid (a,b,c: real; sdiv: integer)	shape
ellipsoid (a,b,c : real)	shape

These functions construct the ellipsoid of “dimension” a, b, and c about origin.

Evaluating Parametric Shapes

Use the commands in this section (through page 8-14) to evaluate points, tangents and normals of parametric curves and parametric surfaces.

Parametric Curves

Given a parametric curve **pc** and a parametric variable **t**, the command for evaluating the point on the parametric curve at **t** is

pnt:= eval_at(pc, t);

where **pnt** is the point on the parametric curve **pc** at **t**.

The command for evaluating the tangent of the parametric curve at **t** is

tangt:= tangent_at(pc, t);

where **tangt** is the tangent of **pc** at **t**.

In SilTools, each shape has a frame known as its **seg_pose**.The **seg_pose** of a shape is the frame that locates the shape from its default location to a desired location in the workcell.

For example, the **seg_pose** of a surface of revolution is at the pose of the World when it is created. However, when the surface of revolution is moved to another location, the **seg_pose** is no longer at the pose of the World. Note that both **eval_at()** and **tangent_at()** evaluate points and tangents at the default location. Therefore, if a parametric shape is moved to a new location, and you wish to evaluate both the point and tangent with respect to this new location, use the following syntax instead:

```
pnt:= seg_pose(pc) * eval_at(pc, t);
tangt:= ornt(seg_pose(pc)) * tangent_at(pc, t);
```

Parametric Surfaces

Given a parametric surface **ps** and parametric variables **u** and **v**, the command for evaluating the point on the parametric surface at [**u,v**] is

```
pnt := eval_at(ps,u,v);
```

The command to evaluate the normal at [**u,v**] is

```
nrm := normal_at(ps, u, v);
```

Considerations regarding **seg_pose** with parametric surfaces are similar to those regarding **seg_pose** with parametric curves. The syntax to evaluate points and normals on a parametric surface **ps** in absolute World coordinates is

```
pnt := seg_pose(ps) * eval_at(ps, u, v);

nrm := ornt(seg_pose(ps)) * normal_at(ps, u, v);
```

Wireframe Models

Operator	Resulting Shape
chain(list(<point1>,<point2>[,...,<pointn>));	open chain

Volume Models

Cylinder

resolution number of facets in circumference of the cylinder (if omitted, **c_circ_res** is used)

angle between 0 and 360 creates partial cylinder

Operator	Resulting Shape
cylinder(<radius>,[<angle>],<height>, [<resolution>]);	cylinder

Block

Operator	Resulting Shape
block(<length>,<width>,<height>);	block

Pipe

radius1 outside radius

radius inside radius

resolution number of trapezoidal prisms in the pipe (if omitted, **c_circ_res** is used)

Operator	Resulting Shape
pipe(<radius1>,<radius2>,<height> [,<resolution>]);	cylindrical volume model with inside and outside radius

Cone

resolution specifies the number of triangular facets in the circumference of the cone (if omitted, the value of the global variable **c_circ_res** is used)

Operator	Resulting Shape
cone(<radius>,<height>[,<resolution>]);	cone

Frustum

radius1	base radius
radius2	top radius
resolution	specifies the number of trapezoidal facets in the circumference of the frustum (if omitted, the value of the global variable **c_circ_res** is used)

Operator	Resulting Shape
frustrum(<radius1>,<radius2>,<height> [,<resolution>]);	truncated cone

Model Operators

In addition to the model constructors, SilTools provides a number of functions which you may apply to models in order to change their characteristics. These functions are called **model operators**. A list of the model operators and a brief description of each follows.

The invert Operator

The **invert** operator returns a model whose facets face in the direction of their original direction. This has the effect of turning the model "inside out."

invert(<shape>);

The glue Operator

The **glue** operator is used to convert a workcell model into a rigid model.

glue('<model_name>');

where **<model_name>** is the name of a model existing in the workcell.

A workcell model may be an object tree which has several child objects. If an object tree is **glue**d, SilTools replaces the tree structure of the object tree with a rigid model. Therefore, you do not have access to any of the children individually once the model is **glue**d.

If the model or any of its children are parametric shapes, **glue** will remove the parametric information about these shapes. For this reason, models which have been **glue**d require less memory space, since SilTools keeps only the discrete information about the shapes—this significantly increases the efficiency of workcell simulation.

You can use glue for shapes which do not exist in the workcell, also

glue('<name>',<shape1>[,...,<shapeN>]);

This version of glue returns a rigid shape **<name>** whose body is the combination of the bodies of **<shape1>** through **<shapeN>**.

IMPORTANT	DO NOT use this command if any of the shapes from **<shape1>** through **<shapeN>** exist in the workcell.

When this version of **glue** is invoked, SilTools defines a reference frame for the resulting shape, and places it on the shape at the same place as the World coordinate frame. This makes it seem as though an invisible copy of the World coordinate frame were included with the shape when it is **glue**d. Because a rigid shape only has one reference frame, any rigid shapes which are subsequently **glue**d lose their reference frames.

The **glue** operator makes no attempt to resolve duplicate elements of the body shape which results. SilTools does not **glue** models with dissimilar body types (wireframe or surface) together; the resulting **glue**d object will consist of two parts: a **glue**d surface and a **glue**d wireframe.

The moveto Operator

The **moveto** operator returns a model which is <**model**> moved to the absolute coordinates <**goal**>. <**goal**> may be either a position (orientation is unchanged), an orientation (position is unchanged), or a complete pose. Note that **moveto** does not redefine the reference frame of the returned model (the reference frame goes with the model).

moveto(<model>,<goal>);

The imoveto Operator

The **imoveto** operator is similar to **moveto**, but does not move the object along a straight line path towards the goal. **imoveto** instantaneously places the object at the goal without consuming any simulated time.

The moveby Operator

The **moveby** operator is similar to **moveto**, but the model value that **moveby** returns is **<model>** moved by the specified **<increment>**. The increment may be a position (orientation is unchanged) and orientation (position is unchanged), or a complete pose. Note that the **<increment>** specified causes an incremental move along or about the axes of the World coordinate frame, not the axes of the **<model>**'s reference frame.

moveby(<model>,<increment>);

IGES Conversions

Although you use the CAD Interfaces panel (displayed by selecting *Import/Export...* from the **Modeling** pulldown menu) for your IGES to SilTools or SilTools to IGES conversions, you can also do so using SIL language commands.

IMPORTANT	You must have the IGES interface installed in your product.

Converting IGES Files to SilTools Models

You may convert IGES model files to SilTools models with the **iges_to_model** function. The variants for this function are listed below.

There are four variants for the **iges_to_model** function:

<filename> is a string giving the pathname of the IGES file to be converted.

<model name> is a string which names the converted model**.**

<level list> is an integer list specifying the levels of the IGES file to be converted.

iges_to_model();

If you do not specify a **<filename>** in this variant, SilTools will prompt you for it. If you specify a **<filename>**, the converted model receives the product identification name from the globals section of the IGES file, and SilTools processes all IGES entity levels.

iges_to_model([<filename>]);
iges_to_model(<filename>,<model name>[,<level list>]);

This variant specifies a level list which will be the only level converted. Specifying a level list prevents SilTools from converting all levels. SilTools will return the **model value** type.

iges_to_model(<filename>,<model name>);

This variant reads all entities and converts all levels.

Converting SilTools Models to IGES files

In order to convert a SilTools model to an IGES file, the model you wish to convert must be in the SilTools product that you are using. If it is not already there, you can bring it into the product with the following function:

restore(<filename>);

where the **<filename>** must be a string. Note that **restore** is a function which returns the value of the model, so it must be assigned a model variable type in order to make use of the returned model.

The command to convert a model to an IGES file is:

model_to_iges(<model>[,<filename>]);

where **<model>** is the variable containing the value of the model to be converted. If you do not specify a **<filename>**, SilTools will prompt you for it during the conversion routine.

After you enter the **model_to_iges** command, SilTools displays a list of IGES global default parameter values, and asks you if any are to be changed. If you answer **yes**, the program steps through these parameters one at a time and asks for changes. If you answer **no**, SilTools prompts you for the name of an IGES file, and converts the model, writing to this file.

Modeling Examples

The following examples illustrate the use of some of the models constructors described above and demonstrate several useful modeling concepts. You are not limited to using SIL commands to create these examples—all of these models could haven been built using the panels.

Example 8.1 Link

The code to create link 1 of the Adept robot is shown below. One way to model this link is to create surfaces of the top and bottom faces and another of the perimeter. You may combine these three surfaces to create a volume model.

To begin, the points which are the vertices of the individual facets between the rounded ends of the link are

```
p1==mk_point(0,radius1,0);
p2==mk_point(0,-radius1,0);
p3==mk_point(side_length,-radius2,0);
p4==mk_point(side_length,radius2,0);
p5==mk_point(0,radius1,height);
p6==mk_point(0,-radius1,height);
p7==mk_point(side_length,-radius2,height);
p8==mk_point(side_length,radius2,height);
```

The interior of the bottom surface is

```
interior==facet(list(p1,p2,p3,p4));
```

The rounded ends of this surface are

```
end1_cap==moveto(mk_cap(radius1,180),mk_ypr(0,0,90));
end2_cap==moveto(mk_cap(radius2,180),
mk_pose(side_length,0,0,0,0,-90));
```

A face is made up of these three surfaces:

```
face1==glue(interior,end1_cap,end2_cap);
face2==copy(face1);
```

(continued on next page)

Example 8.1 Link (continued)

Now you may use this face to create the top and bottom faces of the link by inverting it (bottom) and translating it (top).

```
top_face==moveto(face2,mk_crt(0,0,height));
bottom_face==invert(face1);
```

The rounded facets for the outside surface are

```
end1_surf==moveto(tube(radius1,180,height), mkypr(0,0,90));
end2_surf==moveto(tube(radius2,180,height),
mk_pose(side_length,0,0,0,0,-90));
```

The front and back facets between these two ends are

```
front==facet(list(p5,p8,p4,p1));
back==facet(list(p3,p7,p6,p2));
```

The perimeter is

```
perimeter==glue(front,back,end1_surf,end2_surf);
```

Finally, link 1 is

```
link1_body==glue(top_face,bottom_face,perimeter);
add('link1',link1_body);
```

Example 8.2 Open Box

The **block** constructor creates a model of a block. A constructor for an open box could be written as follows:

```
function openbox(x,y,z:real):shape

var pt1,pt2,pt3,pt4,pt5,pt6,pt7,pt8:point;
bottom,left,right,front,back, outside,inside: shape;

begin
        pt1:=mk_point(0,0,0);
        pt2:=mk_point(x,0,0);
        pt3:=mk_point(x,y,0);
        pt4:=mk_point(0,y,0);
        pt5:=mk_point(0,0,z);
        pt6:=mk_point(x,0,z);
        pt7:=mk_point(x,y,z);
        pt8:=mk_point(0,y,z);
        bottom:=facet(list(pt4,pt3,pt2,pt1));
        left:=facet(list(pt1,pt2,pt6,pt5));
        right:=facet(list(pt3,pt4,pt8,pt7));
        front:=facet(list(pt2,pt3,pt7,pt6));
        back:=facet(list(pt4,pt1,pt5,pt8));
        outside:=glue(bottom,left,right,front,back);
        inside:=copy(outside)
        inside:=invert(inside);
        openbox:=glue(outside,inside);
end;
```

The parameters **<x>**, **<y>**, **<z>** define the length, width, and height of the box respectively, and it is open at the top. Note that the box has both an inside and outside so that it can be viewed from the inside.

For example, if you wished to create an open box with dimensions of [5, 5, 5], you would use the following:

```
box==openbox(5,5,5);
add('openbox',box);
```

Example 8.3 Grid Surface

The following creates a grid surface.

```
procedure hercules();
var gr: grid;
nrows: integer;
ncols: integer;
j: integer;
temp:real;
parent_shp: shape;
comp_shp: gsurface;
    comp_shp2: gsurface;

begin

    nrows:=6;
    ncols:= 17;
    gr:= mk_grid(nrows, ncols);

    for j:= 0 to 16 do
    begin
    temp:= float(j);

    gr[0,j]:= mk_point(0.0, 2.25*temp, 9.0) * inch;
    gr[1,j]:= mk_point(7.395, 2.25*temp, 9.0) *inch;
    gr[2,j]:= mk_point (9.0,2.25*temp,7.395)*inch;
    gr[3,j]:= mk_point(9.0,2.25*temp,-7.395)*inch;
    gr[4,j]:= mk_point(7.395, 2.25*temp, -9.0) *inch;
    gr[5,j]:= mk_point(0.0, 2.25*temp, -9.0)*inch;
    end;

    comp_shp:= mk_gsurface (gr);
    comp_shp2:= mk_gsurface(gr);
    moveto(comp_shp2, mk_ypr(0,0,180.0));
    moveto(comp_shp2, mk_point(0,36.00*inch,0.0));
    parent_shp:= mk_empty_shape();
    add('hercules',parent_shp);
    add('side1',comp_shp);
    adopt('hercules', 'side1');
    add('side2', comp_shp2);
    adopt('hercules','side2');
end;
```

Example 8.4 Hollow Cylinder

The following creates a hollow cylinder using **mk_rsurf** (ruled surface).

```
function hollow_cyl(radius, height: real): shape;
var circle1, circle2: pcurve;
   outside, inside: shape;
begin

     circle1:= circle(radius) as_type pcurve;
     circle2:= circle(radius) as_type pcurve;
     moveto(circle2, mk_crt(0,0,height));
     {Create a ruled surface}
     outside:= mk_rsurf(list(circle1), list(circle2));
     inside:= copy(outside);
     inside:= invert(inside);
     {Note, by calling glue, the parametric informations of the ruled
surface is destroyed.}
     hollow_cyl:= glue(outside, inside);

end;
```

To create a hollow cylinder into the workcell:

```
temp== hollow_cyl(<radius>, <height>);
add('<name>', temp);
```

Example 8.5 Sphere

The following creates a sphere using **mk_rvsurf** (surface of revolution.):

```
function sphere(radius: real): shape;
var arc_shp: pcurve;
begin
     arc_shp:= arc(radius, 180.0) as_type pcurve;
     moveto(arc_shp, mk_ypr(0.0,90.0,0.0));
     sphere:= mk_rvsurf(list(arc_shp));
end;
```

To create a sphere in the workcell:

```
temp== sphere(<radius>);
add('<name>',temp);
```

Example 8.6 Bottle Shape

The following creates a bottle shape using **mk_rsurf** and **mk_rvsurf**.

```
cir1==circle(1.0) as_type pcurve;
cir2==circle(1.0) as_type pcurve;
moveto(cir1, mk_crt(0.0,0.0,11.0));
moveto(cir2, mk_crt(0.0,0.0,10.0));

ruled_surf1== mk_rsurf(list(cir2), list(cir1));

cir3 == circle(3.0) as_type pcurve;
moveto(cir3, mk_crt(0.0, 0.0, 7.0));

ruled_surf2 == mk_rsurf(list(cir3), list(cir2));

pt1== mk_point(0.0,0.0,0.0);
pt2== mk_point(0.0,3.0,.0.0);
pt3== mk_point(0.0,3.0,7.0);

ary== mk_array(pt1, pt2, pt3);
pcrv== mk_rctcurve(ary) as_type pcurve;

revsurf== mk_rvsurf(list(pcrv));

bottle == mk_empty_shape();
add('bottle',bottle);

name(ruled_surf1,'neck');
name(ruled_surf2,'shoulder');
name(revsurf,'body');
add_below(ruled_surf1, bottle);
add_below(ruled_surf2, bottle);
add_below(revsurf, bottle);

paint('bottle', green);
```

Chapter 9

Advanced Data Types

This chapter describes supertypes, metatypes, SIL constants and C data types.

System-Defined Types

SIL system-defined types include the basic scalar types: **integer**, **real**, **boolean**, **string**. But SIL also provides some fairly exotic types. For example, internal representations of SIL expressions and their components are also ordinary SIL data objects which can be manipulated by SIL programs the same way that scalars can. These are called **metaobjects**, and the types to which they belong are called **metatypes**.

Another category of useful system-defined types is the **supertypes**. If we think of types as sets of values, then all types can be regarded as subsets of the supertypes. The two supertypes are **lispob** and **universal**.

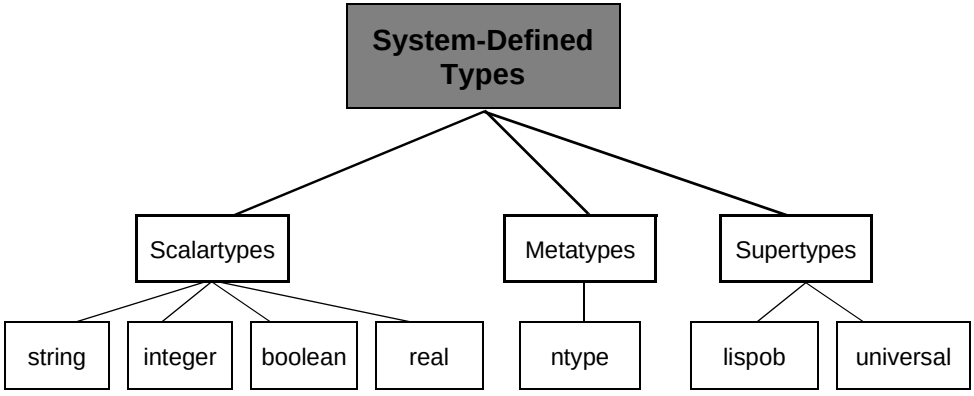


Figure 9-1 System-defined type classifications

NOTE "Strings" on page 4-12 describes strings. The complete SIL data type structure is shown in Figure 1-5, "Data type classifications" on page 1-11.

ntype

The type **ntype**, the "type of all types", can be defined grammatically by

```
<ntype> ::= <dtype> | <polymorphic type>
<dtype> ::= <primitive type> | <constructed type>
<primitive type> ::= <user defined type> | <atomic type>
<atomic type> ::= <scalar type> | <metatype> | <supertype>
<scalar type> ::= integer | boolean | char | string | real
<metatype> ::= id | sconst | ntype | tform | iform | net | event | …
<supertype> ::= universal | lispob
<constructed type> ::= array_of(<dtype>) | list_of(<dtype>)
            | sarray_of(<dtype>)
            | closure(<return type>,<input type>,...,<input type>)
            | tclosure(<return type>,<input type>,...,<input type>)
<polymorphic type> ::= function(<return type>,<input
type>,...,<input type>)
            | procedure(<input type>,...,<input type>)
            | task(<return type>,<input type>,...,<input type>)
<input type> ::= <dtype>
<return type> ::= <dtype>
```

Notice that **ntype** appears to be a member of itself. However, it is really the syntactic expression **ntype** that is a member of the data type **ntype**, so Russell's paradox is avoided.

Type Expressions

An interesting feature of SIL is that type expressions like **integer** and **list_of(array_of(real))** are data objects themselves. Thus, we can create and evaluate expressions like

foo == integer or **foo = integer**

All type expressions are **ntype**. This may seem a little paradoxical (i.e., can we define the type of all types that are not members of themselves?) until you realize that type expressions are just syntactic entities that evaluate to types.

Example 9.1

An **integer predicate** type is any type of the form

function(boolean, integer, …, integer)

The following is a predicate that determines if a type is an integer predicate type:

```
function integer_predicate_type(tp: ntype): boolean;
    var temp: boolean;
     begin
     temp := is_function(tp) and (result_type(tp) = boolean);
     if temp then
         for i in input_types(tp)
              while temp do
                   temp := (i=integer);
     integer_predicate_type := temp
     end;
```

The following is a partial list of the primitive operations on **ntype**. The names of the functions are self-documenting:

```
function is_primitive (n:ntype):boolean;
function is_reptyp (n:ntype):boolean;
function is_array (n:ntype):boolean;
function is_list (n:ntype):boolean;
function rep_of(n:ntype):ntype; { assumes n is represented type }
function list_subtype(x:ntype):ntype;
function subtype(x:ntype):ntype;
function subtypes(x:ntype):list_of_ntype;
function mk_list_type(x:ntype): ntype;
function mk_array_type(x:ntype): ntype;
function is_function (n:ntype):boolean;
```

Assume **x** = result type, **y** = input types:

```
function mk_function_type(x:ntype;y:list_of_ntype): ntype;
                { assumes a real function type is the input: }
function is_task(x:sconst):boolean;
function is_closure(x:sconst):boolean;
function is_tclosure(x:sconst):boolean;
function input_types(x:ntype):list_of_ntype;
function result_type(x:ntype):ntype;
```

lispobs

The type **lispob** is the SIL type whose values include all SIL values (**lispob** was derived from **LISP OB**ject).

Any expression can be **as_typed** to **lispob**, and a **lispob** can be **as_typed** to any type. So, **lispob**s offer a kind of escape from the usually strong typing of the SIL type system into a domain of untyped data similar to that of Lisp. The type ***char** plays a similar role in C to that of **lispob** in SIL, in that it is conventionally used to designate a "raw pointer" to data of unspecified type. So,

```
(3 as_type lispob) as_type integer;
```

is a legal SIL expression with value 3. An **as_type** from **lispob**, although always legal as a SIL expression, may generate problems at runtime if the format of the **lispob** datum does not agree with that required by the type to which it is being cast. For example,

```
aa == ('a' as_type lispob) as_type rri_lrec;
```

will result in a value which SIL "thinks" is an **rri_lrec**, but is really a string. The consequences of such a miscast can be serious. For example,

```
aa . f1 := 4.5;
```

will smash the memory location just after the tag in **aa** with 4.5, since **aa** is really a string, whose first word past the tag is a length field. Filling this field with the bits for 4.5 results in a corrupted string data structure, and this in turn will generate garbage collection errors. So, you should be very careful when using **as_type**, just as the C programmer needs to exercise care when using the C cast operation.

When a **heapval** (i.e., a value which is not a record, nor an integer or real) is **as_typed** to the type **lispob**, this amounts only to a compile time assertion of type—it does not induce any actual runtime operation. When a **stackval** is **as_typed** to **lispob**, it is copied into the heap.

The constant NIL of type **lispob** can be used to represent a null or undefined value for any **lispob** type. The predicate

```
null(x: lispob): boolean;
```

tests for equality to NIL.

nul(x: <type>): boolean;

for any **<type>** is equivalent to

null(x as_type ob);

So, for example,

nul(nil as_type rri_lrec);

will return TRUE.

lispob Operations

Pair constructor:

```
function cons(x, y: lispob): lispob
    cons(x, y) = (x . y)
```

Pair selectors:

```
function car(x: lispob): lispob
    car((x . y)) = x

function cdr(x: lispob): lispob
    cdr((x . y)) = y
```

These operations will be familiar to Lisp programmers, as will the following abbreviations for common compositions of **car** and **cdr**:

cadr(x) abbreviates **car(cdr(x))**
caddr(x) abbreviates **car(cdr(cdr(x)))**
cddr(x) abbreviates **cdr(cdr(x))**
etc.

Pair mutators:

procedure set_car(x, y: lispob) changes **car(x)** to **y**
procedure set_cdr(x, y: lispob) changes **cdr(x)** to **y**

Predicates (used to test for equality between two **lispob**s):

function eq(x, y: lispob): boolean

Here are some operations that use the tag of a **lispob** datum to extract some basic information.

```
function is_real(x: lispob): boolean
function is_integer(x: lispob): boolean
function is_string(x: lispob): boolean
function is_pair(x: lispob): boolean
```

Finally, **ob** is short for **lispob**, i.e., **ob == lispob**.

Represented Types

Suppose that we want to introduce a new type called **degree** to be used in representing angles. This can be done with the declaration

```
type degree = real;;
```

degree is a new type that is distinct from real, but its data values are represented by reals. Another syntax for the same declaration is

```
real represents degree;
```

Initially, no operations are defined on **degree**, since it is a new type. Since **real** and **degree** have the same format for their data, **as_type** can be used to get back and forth between **real** and **degree** (illustrated in Example 9.2).

Example 9.2

```
function plus(x,y:degree): degree;
    begin
    plus := ((x as_type real) + (y as_type real)) as_type degree;
    end;


SIL>  (34.0 as_type degree) + (350.0 as_type degree);
24.0
```

Universals

All SIL data tagged by type is type **universal**. As with **lispob**, any SIL expression can be cast to **universal** and back.

Consider the following situation. A robot can assemble three types of parts:

```
procedure assemble(part: top_part);
procedure assemble(part: middle_part);
procedure assemble(part: bottom_part);
```

A **dispatch** procedure identifies the part and invokes the appropriate assembly routine. But how do we define the dispatch routine? If we assume that the part is a parameter to dispatch, how can we know which type it will be?

```
procedure dispatch(part: ???_part);
```

We could declare **part** to be a **lispob**:

```
procedure dispatch(part: lispob);
```

but then we would not have any way of figuring out the type of the part later when we need to call the proper assemble procedure. One solution to this dilemma is to use **universal**s. A **universal** is a type tagged **lispob** implemented as a SIL type:

```
type universal = lrecord
    value_of: lispob;
    type_of: ntype
    end
```

Like any other records, **universal**s can be constructed either by using the automatically-defined constructor: **mk_universal** or by using **as_type**.

Assume **var u: universal;;** then

```
u := 3 as_type universal;
```

is equivalent to

```
u := mk_universal(3 as_type lispob, integer)
```

Furthermore, **as_type** can be used to cast **u** back to an integer. Assume:

```
var n: integer;;
```

then

```
n := u as_type integer;
```

If **u** were not an integer, the above statement would generate an error.

Applying Procedures

To write a dispatch procedure using **universal**s, we need to answer one more question: assuming that all parts will be represented as **universal**s, how do we apply the appropriate assemble procedure? This is accomplished with the **apply** operator:

> **function apply(op: id; arg1, arg2, … :): universal**
> where **op** is the name of an operator, and **arg1, arg2**, … are the arguments to **op**.

For example:

Example 9.3

apply("plus, 3 as_type universal, 4 as_type universal)

will return **7** tagged as a **universal**, while

apply("plus,[1,2,3] as point as_type universal,[2,4,6] as point as_type universal)

will return the point **[3,6,9]** as a **universal**.

Another example:

Example 9.4

```
function twice(x:universal):universal;
    begin
    twice := apply("plus,x,x);
    end;
```

will double any type of input.

The **apply** operator will generate an error if no appropriate variant is found.

The arguments to **apply** need not all be **universal**s. For example, the following arguments used with **apply** would be successful:

```
apply("plus, 3 as_type universal, 4)
```

The **apply** operator provides what is called **late binding**. Late binding means that the decision as to which variant of a function is designated by a function name is made at the latest possible moment—when the function application is actually being executed. Ordinary function application in SIL is of the **early binding** style: the selection of variant is made at the earliest possible time—when the code is read in. Early binding has the advantage of being efficient, since the variant selection effort happens only once before the code is executed. Late binding, however, provides the flexibility of allowing the same code to treat various types of inputs. In object-oriented terminology, variant selection is referred to as *binding of methods to messages*—hence the names early binding and late binding. Among object-oriented languages, C++ uses early binding for all but virtual functions, while SmallTalk and Objective C always employ late binding.

We are now ready to write **dispatch**:

```
procedure dispatch(part: universal);
    begin
    apply("assemble, part)
    end
```

A call to dispatch would look like

dispatch(part as_type universal)

Example 9.5

Assume there are three variants of a procedure **foo**:

```
procedure foo(x: integer);
    begin
    writeln('inside integer variant of foo')
    end;

procedure foo(x: string);
    begin
    writeln('inside string variant of foo')
    end;

 procedure foo(x: boolean);
    begin
    writeln('inside boolean variant of foo')
    end;
```

```
SIL> apply("foo, 3 as_type universal);
inside integer variant of foo [UNIVERSAL:
NIL OF_TYPE LISPOB]

SIL> apply("foo, 'arf' as_type universal);
inside string variant of foo [UNIVERSAL:
NIL OF_TYPE LISPOB]
```

When no variant can be found:

```
SIL> apply("foo, 4.1);
error: no variant available for universal
apply of FOO
```

The **applyn** operator works in a similar fashion, but it returns a failure indicator when no variant is found. The function **is_fail** determines whether or not a universal value indicates failure.

Example 9.6

```
SIL>  u == applyn("foo, list(4.1 as_type universal));
SIL>  is_fail(u);
TRUE
```

Applications

Applications are entities that remember a function and a list of arguments. They are similar to closures, with the added feature of an argument list that can be stored and passed to the function when the application is executed.

Example 9.7

```
procedure write_stars(x:integer);
var
    i : integer;
begin
     for i :=1 to x do
         writeln('*****');
end;

myapp == mk_application("write_stars,list(3 as_type universal));
and now
SIL>  execute(myapp);
  *****
  *****
  *****
```

This function constructs an application:

```
function mk_application(fn : id; args : list of universal) :
                                        application;
```

An application contains the identification (**id**) of a function and the arguments to be passed to it when executed.

This function executes an application:

```
function execute(app: application):universal;
```

The application function is called with the included arguments.

Casting

In SIL, an expression's type can be modified by the **as_type** operator. The effect of this operator is analogous to that of the C cast primitive—it asserts that the value of the expression should be treated as belonging to a specified type, whatever the type originally assigned to the expression may have been. The syntax is

<expression> as_type <type>

This has a similar meaning to the C syntax

(<type>)expression

Not all **as_types** are legal. The rule (which has a few exceptions given later) is that the data format of the value to be cast must agree with the data format of the type to which it is being cast. Another restriction is that a record cannot be cast to an **lrecord**, nor an **lrecord** to a record (illustrated in Example 9.8).

Example 9.8

type type_a = lrecord xc: real;yc: real;zc: integer;end;;

Then any value of type **type_a** can be legally **as_typed** to the **rri_lrec** given above, but not to **rri_rec**, nor to **i_rri_lrec**.

Efficiency Considerations

In this section, we consider the efficiency of casting (**as_type**), and of the various kinds of applications of function-like objects to their inputs. Most casting is free, in the sense that it results in no runtime code. Casting of integers, reals, and records (but not **lrecord**s) to **lispob** requires copying the object in question into the "heap". **lrecord**s, strings, **id**s, and booleans are already in the heap, so can be cast to **lispob** for free. Casting to **universal** requires adding a type tag (except in the case of objects—see "Object-Oriented Terminology" on page 5-1).

In this chapter, we have introduced several ways of applying a function-like object to a list of inputs. There are substantial differences in efficiency between the various kinds of applications. The ranking, from fastest to slowest, is

1. "Ordinary" function application (e.g., **twice(4)**). This is the fastest of all, and, when compiled, is equivalent in efficiency to a C function application.
2. Closure application (e.g., **shorterc('a','ab')**). This is almost exactly as fast as ordinary function applications—it is equivalent to the application of an indirect function in C. The only overhead is chasing a pointer to a function.
3. Application of an **sconst**, as in

   ```
   apply(vp,list(2 as_type ob,3 as_type ob))
   ```

   The application itself is just as fast as a closure application. However, in this example, there is some overhead for the casting to **lispob**.
4. Application of an **id** to a list of **universal**s, as in

   ```
   apply("plus,3 as_type universal,4);
   ```

   This could be considerably more expensive than the other kinds of **apply**, because it involves searching at runtime through the variants of **plus** for one that works.

SIL Constants

All SIL definitions have internal representations called **sconst**s (SIL constants). An **sconst** is like a descriptor which contains type, name, and value fields for the defined object.

Because SIL is a polymorphic language, a single id **x** can be the name of several **sconst**s. However, only one of these **sconst**s can represent a non-function type. This **sconst** is the *data* variant of **x**; the other **sconst**s are the *function* variants of **x**. The following operators help locate an **sconst** using an **id**:

```
function data_variant(x:id): sconst;
function has_data_variant(x:id): boolean;
function function_variants(x:id): list of sconst;
function has_function_variant(x:id): boolean;
```

Because two function variants with the same name must have distinct input types, a name and a list of input types uniquely specify an **sconst** for a function variant. We can fetch this **sconst** with

```
function find_variant(x: id; intps: list of ntype): sconst;
```

More generally, an **id** and a type specify an **sconst** which can be fetched by

```
function find_variant(x: id; tp: ntype): sconst;
```

If there is no variant of the indicated type, a special **sconst**, **undefined_sconst** is returned. To test for **undefined_sconst**

```
function is_undefined(x:sconst):boolean;
```

This function applies the given **sconst** to the given arguments:

```
apply(op:sconst:a:list of lispob);
```

For example:

Example 9.9

```
SIL> vp==find_variant("plus,list(integer,integer))
SIL> apply (vp,list(3 as_type ob, 4 as_type ob))
```

C Data Types

C Records and C Arrays

Any SIL record or **lrecord** includes a tag word at the beginning for use by the garbage collector. Any SIL array or string has such a tag word too, as well as a length field. The **crecord** facility in SIL allows records and arrays to be declared without including these additional tag words and length fields. The main motivation for this is to allow direct manipulation by SIL code of any C data structure.

The syntax of a **crecord** declaration is just like that of a record or **lrecord**:

```
type erb = crecord
xc: integer;
yc: real;
end;;
```

This is identical in effect to the C declaration:

```
struct erb {  int xc;   double yc;  }:
```

then

```
new(erb);
```

returns a value of type

```
^erb
```

i.e., pointer to **erb**, which is equivalent to the C type ***erb**.

The usual SIL syntax can be used to select and set the fields of an **erb**:

```
ee == new(erb); ee . xc := 56; ee .yc := 5.4 + ee . xc;
```

Similarly, a **carray** is an array without tag or length fields. A **carray** can be created with

```
cc == carray_create(integer,10);
```

The "**^**" syntax can be used to make a pointer, as in

```
aa == ^(ee . xc);
```

or

```
aa == ^cc[4];
```

The type of **aa** is **^integer**. The only legal arguments to **^** are fields of **crecord**s and entries in **carray**s. Pointers are de-referenced as follows:

```
aa^;
```

then

```
aa^ := aa^ + aa^;
```

will double the integer value pointed to by **a**.

crecords and **carray**s can be built from the primitive types **cchar**, **cshort**, **integer**, **real**, **sreal** or from other **crecord**s or **carray**s, but not from other SIL types. For example,

```
type oo == crecord my_ob:lispob; my_point:point; end;;
```

is illegal twice over.

SIL Type	Identical to C Type
cchar	**char**
cshort	**short**
sreal	**float** (single precision real)
integer	**int**
real	**double**

The types **cchar**, **cshort**, and **sreal** should appear only as the subtypes of **carray**s, pointers, or **crecord**s, as in

```
type noo = crecord
my_char: cchar;
my_sreal: sreal;
my_thing: carray_of(cshort);
end;;
```

Alignment is done as in C—each type is aligned to an even multiple of its length.

cchars and **cshorts** when extracted turn into SIL integers, and **sreals** into SIL reals (illustrated in Example 9.10).

Example 9.10

```
nn == new(noo);
nn . my_char := 45; { use an integer, not a char or cchar }
nn . my_char;       { returns an integer }
```


C Strings

There are a couple of utilities for going back and forth between SIL **lstring**s and C strings.

REMINDER

An **lstring** is a string (called the contents) together with an associated length which specifies the part of the contents in use. See “lstrings” on page 4-15 for more information.

The type **cstring** is defined just to be a synonym for **carray_of(cchar)**. The following operations are provided:

```
function to_cstring(x: lstring): cstring;
```

This first checks that the contents string of **x** is **static** (does not get moved around by the garbage collector) and null-terminated. If either of these conditions is violated, a new contents which is tenured and null-terminated is generated and set up as the contents part of **x**. The **cstring** returned is a pointer to the “raw” (untagged) contents of **x**. So,

the **cstring** will occupy the same storage as the contents of **x**, and will be null-terminated. Since the storage for the resulting **cstring** cannot be freed, this function should be used only to create permanent **cstring**s.

The following function statically allocates a brand-new null-terminated **cstring** with capacity equal to that of **x**, and copies **x** into it. Since the storage for the resulting **cstring** cannot be freed, this function should be used only to create permanent **cstring**s.

```
function mk_cstring(x: lstring): cstring;
```

REMINDER The capacity of an **lstring** is usually bigger than its current length.

The following function dynamically allocates a brand-new null-terminated **cstring** with capacity equal to that of **x**, and copies **x** into it. The storage for the resulting **cstring** can be freed with **free_cstring**.

```
function new_cstring(x: lstring); cstring;
```

This procedure frees the **x cstring**, which has been created dynamically by **new_cstring**:

```
procedure free_cstring(x: cstring);
```

This procedure copies **c** to **x**, stopping at a null in **c**, or the capacity of **x**, whichever comes first:

```
procedure copyto(x: lstring;c: cstring);
```

The following procedure copies **x** into **c**. Since **c** has no length indication, this can be dangerous—if **c** was allocated to be shorter than the current length of **x**, then the memory after **c**'s length allocation will be deleted.

```
procedure copyto(c: cstring;x: lstring);
```

The print function for **cstring**s will print characters until a null is hit, or the limit **max_cstring_print_length** is reached.
max_cstring_print_length is initially 100.

If you want to allocate an **lstring** to be passed to C, you may wish to use

```
function mk_static_lstring(x: string;n: integer): lstring;
or
function mk_static_lstring(x: string): lstring;
```

Either of the above functions are used to construct **lstring**s that are already static and null terminated.

This procedure will cause the contents of **x** to become static and null terminated (if they are not already):

```
procedure mk_static(x: lstring);
```


C Constants at Build Time

NOTE "Builds" are described in Chapter 11, "Working with SIL Code".

C data structures cannot be safely created at build time (except as described below). For example, if you compile a file in which the line

```
aa == mk_cstring('abc');
```

appears, and then start up the resulting state, **aa** will contain garbage. This is because starting a state almost always moves the heap, so that the pointer that is the value of **aa** is no longer valid. To get around the problem, use this construct instead:

```
cstring_constant(aa,'abc');
```

This has exactly the same effect as

```
aa == mk_cstring('abc');
```

except that **cstring_constant** records the need to reset **aa** when a state starts up, making it safe for use in compiled code.

Chapter 10

Concurrency

This chapter explains how to use SIL for concurrent execution of multiple tasks within one “state” or data space.

Temporal & Instantaneous Commands

SIL maintains a global variable called **clock** which measures the passing of simulated time. Certain SIL commands cause **clock** to be advanced when they are called. Commands that consume simulated time are called **temporal**. Non-temporal commands are called **instantaneous**. A block of instantaneous commands is called an **instantaneous block**.

Temporal commands are useful in simulations that model time. For example, SilTools commands that move or operate simulated kinematic devices, like machines or tools, are temporal.

All SIL function and procedure calls are instantaneous. Therefore, no temporal commands can be called in the body of a function or procedure. Procedures intended for concurrent execution are indicated by using the keyword **task** rather than the keywords **function** or **procedure**. Tasks may include any code which would be legal in a procedure or function, and may include primitives for synchronization. The syntax for defining a task is similar to the syntax for defining functions and procedures:

```
task <name>([<formal parameters>])[: <type>];
    [<local variable declarations>]
    <task body>;
```

where **<task body>** is either a procedure or function body, depending on whether or not a return value is indicated.

IMPORTANT	Do not confuse simulated time with real time. For example, calling a procedure containing an infinite loop will consume an infinite amount of real time, but 0 seconds of simulated time!

Of course, calling any temporal command from inside of a task will cause the task to consume simulated time. Therefore, tasks which call temporal commands are themselves temporal commands. In fact, the body of a task can be viewed as being composed of several instantaneous blocks separated by calls to temporal commands.

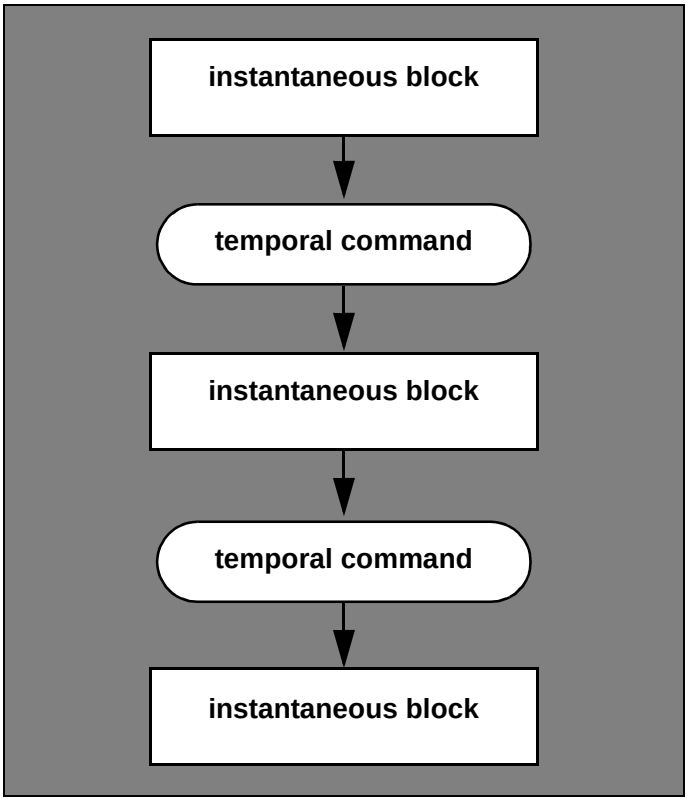


Figure 10-1 Typical control flow for a task

Delay

The simplest way to consume simulated time from inside of a task is to call the most primitive temporal command:

delay(<seconds>)

When called from inside of a task **foo**, **delay** will cause **foo** to suspend itself until the clock has advanced the indicated number of seconds.

Example 10.1 defines a temporal command.

Example 10.1

In this example, a new temporal command, **notify**, is defined.

```
task notify(msg: string);
    begin
    for i := 1 to 4 do
        begin
        delay(2.0);
        writein(msg, ' at clock = ', clock);
        end
    end;;
```

The **notify** command will consume eight simulated seconds each time it is called. Assume **clock = 10.0** when **notify('hi')** is called:

```
hi at clock = 12.0
hi at clock = 14.0
hi at clock = 16.0
hi at clock = 18.0
```


The Scheduler

The body of a task can be viewed as a sequence of blocks consisting of a sequence of instantaneous commands terminated by a temporal command. The **Scheduler** is a SilTools program that simulates concurrent execution of tasks by interleaving the execution of blocks from two or more tasks. Tasks wait in the run queue to have their next block executed. The terminating temporal command of a block suspends or reschedules (i.e., places at the end of the run queue) the current task, and returns control to the scheduler which begins executing the next block from the next task in the run queue. This continues until all tasks are suspended and the run queue is empty. Since **clock** never advances during execution of these instantaneous blocks, the blocks have executed concurrently in simulated time. Since all tasks are now suspended, everything that could possibly happen in that simulated instant has happened and the **clock** advances.

Delayed tasks (i.e., tasks that have suspended themselves for a specific length of time) wait in a queue of delayed tasks prioritized by wake up times. When all tasks are suspended and the run queue is empty, the scheduler advances **clock** to the wakeup time of the next task on the delay queue and resumes execution of this task.

Start and Run

Although a single task can be executed by calling it in the same manner as a function or procedure, it will not work when executing many tasks concurrently. To do this, you need to first place the tasks to be executed in the run queue by using the **start** command:

start("<task> [, <arg>, …, <arg>]);

where **<arg>, …, <arg>** are optional arguments to **<task>**.

Example 10.2

In this example, assume **t1**, **t2**, and **t3** are tasks which accept integers.

```
SIL>begin
    start("t1,0);
    start("t2,1);
    start("t3,2);
    end;
```

adds **t1**, **t2**, and **t3** to the run queue with the given inputs. In Text Mode,

run();

initiates their concurrent execution.

NOTE

The behavior of tasks run differs slightly depending on if you are programming using the menus or in Text Mode. When using the menus, the Scheduler is active whenever tasks have been started or called. In Text Mode, the Scheduler is activated only by explicitly calling a task or executing the following command:

run();

The **start** command may be used at the top level or within a task. Use the **run** command only at the top level.

Example 10.3

```
task foo1();
    begin
    writeln('foo1 sleeping at ',clock);
    delay(2.0);
    writeln('foo1 waking at ',clock);
    end;

task foo2();
    begin
    writeln('foo2 calling foo1 at ',clock);
    foo1();
    writeln('foo1 returned at ',clock);
    delay(1.0);
    writeln('foo2 starting foo1 at ',clock);
    start(''foo1);
    writeln('foo2 sleeping at ',clock);
    delay(1.5);
    writeln('foo2 waking at ',clock);
    end;
```

Then **foo2();** results in the following output:

```
foo2 calling foo1 at 0.000000
foo1 sleeping at 0.000000
foo1 waking at 2.000000
foo1 returned at 2.000000
foo2 starting foo1 at 3.000000
foo2 sleeping again at 3.000000
foo1 sleeping at 3.000000
foo2 waking at 4.500000
foo1 waking at 5.000000
```

NOTE

If the global flag

sched_verbose

is set to true, then the scheduler will print out a very detailed account of its activities—one descriptive line for every task call, start, return and delay.

Tickers

Tickers are instantaneous commands that run at regular intervals during a simulation. Care must be taken when writing a ticker—if it is computationally intensive, or runs too often, the simulation may slow considerably.

Tickers are useful for gathering data during a simulation, and for applying rules and laws to the simulated environment.

This function constructs a ticker which runs an application at the given interval of the simulation clock:

```
function mk_ticker(app : application; intv : real):ticker;
```

where **app** is an application to run, and **intv** is the time interval at which to run.

NOTE Applications are described in “Applications” on page 9-11.

These procedures start and stop a ticker:

```
procedure activate(tck : ticker);
procedure deactivate(tck : ticker);
```

Semaphores

The basic synchronization mechanism in SIL is the **semaphore**. Other methods of synchronization, such as pipes and process lines, are available, but they all depend on semaphores. **semaphore** is a SIL type, with the following operations:

```
wait(<semaphore>);
signal(<semaphore>);
value(<semaphore>):integer;
new_semaphore():semaphore;
```

A semaphore **s** with value **n** may be thought of as representing **n** units of some resource. The **wait(s)** operation, when executed by a task, is a request for one unit of the resource. If the value of the semaphore is greater than 0, then the value is simply reduced by 1, and the wait returns. If, however, the value is 0 when **wait(s)** is executed, the task which executes the wait is suspended until some other task makes a unit of the resource available. If other tasks are already waiting for the resource (that is, have executed **wait(s)**), then our task is added to the end of a queue associated with the semaphore.

The command **signal(s)** adds a unit of resource to the semaphore. If there is a queue of tasks waiting for the resource, the first element of the queue is resumed. If no tasks are waiting, the value of the semaphore is incremented.

Example 10.4

Suppose that two factory robots, **P1** and **P2** are moving parts to a location **L** from which two other devices **C1** and **C2** are removing them for processing. Assume further that parts can be stacked at **L** (for simplicity in this example, we assume that the number of parts which can be stacked is unlimited). Synchronization between tasks which simulate these devices can be achieved using semaphores, as in the code shown in this example.

Assume that **P1_puts_part** is a task which **P1** can execute to put a part at the location, and then retract from the location. Similarly, assume that **C1_gets_part** is a task which **C1** executes to get a part from the location. Finally, assume similar capabilities for **P2_puts_part** and **C2_gets_part**. We assume that it is dangerous to execute more than one of these tasks at the same time because of the potential for collisions.

We use two semaphores:

- **parts_at_L** which represents the availability of parts at **L**.
- **L_is_clear** which represents the proposition that **L**'s vicinity is clear of obstructions that may cause a collision.

continued on next page

Example 10.4 (continued)

L_is_clear represents the "resource" of clear space around **L**, of which there is only one unit. **L_is_clear** is called a binary semaphore. A binary semaphore is one whose value never exceeds one, and which typically represents a proposition which is either true or false. The following code uses semaphores to ensure that our four devices will properly synchronize their activities:

```
parts_at_L == new_semaphore();
L_is_clear == new_semaphore();
signal(L_is_clear); { initially, L is clear}

task P1();
    begin
    while true do
        begin
        wait(L_is_clear);
        P1_puts_part();
        signal(parts_at_L);
        signal(L_is_clear);
        end;
    end;

task P2();
    begin
    while true do
        begin
        wait(L_is_clear);
        P2_puts_part();
        signal(parts_at_L);
        signal(L_is_clear);
        end;
    end;
```

continued on next page

Example 10.4 (continued)

```
task C1();
    begin
    while true do
        begin
        wait(parts_at_L);
        wait(L_is_clear);
        C1_gets_part();
        signal(L_is_clear);
        end;
    end;

task C2();
    begin
    while true do
        begin
        wait(parts_at_L);
        wait(L_is_clear);
        C2_gets_part();
        signal(L_is_clear);
        end;
    end;
```

In Example 10.4, **value(parts_at_L)** will always be the number of parts at **L**. Note that a little thought is required to verify the correctness of even this simple example. Suppose that when **C1** waits for **parts_at_L**, a part is available. In the course of waiting for **L** to be clear, however, that part is taken away. Such an occurrence would represent a failure of synchronization. This scenario will not occur, since when **C1** waits for **parts_at_L**, the execution of the wait decrements **parts_at_L**. This decrement, in effect, reserves a part for **C1** which no other task can take away.

Exercise

Suppose that only **N** parts will fit at **L**. Modify the code in Example 10.2 to satisfy this constraint.

Hint: introduce a semaphore **L_space_available** which represents the number of parts (in addition to the parts already there) that can be put at **L** (so that **value(L) + value(L_space_available) = N**).

Pipes

Pipes are used for communication between tasks. A pipe of type **pipe(<type>)** is a structure of the form:

```
pipe =lrecord
    messages: queue of <type>;
    waiters: queue of tasks
    end;
```

Example 10.5

An integer pipe is a structure of the form:

```
pipe = lrecord
    messages: queue of integer;
    waiters: queue of tasks
    end;
```

Tasks can either place messages at the end of the **messages** queue of a pipe, or remove messages from the front of the **messages** queue. If a task tries to remove a message when the **messages** queue is empty, then the task suspends itself on the **waiters** queue of the pipe until a message arrives. Note that **messages** does not have specific tasks as destinations.

To create a pipe of type **<type>** we use the **new_pipe** command:

```
p == new_pipe(<type>);
```

To place a message **<msg>** of type **<type>** in **p** we use **signal**:

```
signal(<msg>, p)
```

If the **waiters** queue is empty, then **signal** simply adds **<msg>** to the **messages** queue of **p**. If the **waiters** queue is not empty, the **messages** queue will be empty, and **signal** wakes up the first task on the **waiters** queue and personally delivers **<msg>**.

The **wait** command returns the next message in a pipe, if there is one. Otherwise, it will suspend the current task and add it to the **waiters** queue. Both **wait** and **signal** are temporal commands that return control to the scheduler when they complete.

Example 10.6

```
p==new_pipe(integer);

task sender(n:integer);
    begin
    for i := 1 to n do
        begin
        delay(1);
        signal(i, p);
        end;
    end;

task receiver();
var w: integer;
    begin
    while true do
        begin
        w := wait(p);
        writeln('at ',clock,' received ',w);
        end;
    end;

start("sender, 10);
start("receiver);
run();
```

Processes and tclosures

When a task places a message in a pipe there is no guarantee as to which task will receive this message, since any task can extract messages from any pipe. Alternatively, a task can have private pipes. While any task can place a message in a private pipe, only the owner task can extract messages from the pipe.

Tasks with private pipes are, for the purpose of compatibility with pre-4.2 releases, called **processes**. Processes are parameterless tasks that do not return values. The syntax for defining a process is a little different from the syntax used for defining tasks:

process <name>([<private pipes>]);
[<local variable declarations>]
<task body>;

where

<private pipe> ::= <pipe name>[, <pipe name>, …, <pipe name>]: <type>

and

<private pipes> ::= <private pipe>, …, <private pipe>

The key word **process** alerts the task-defining machine that the parameters are to be interpreted as private pipes rather than parameters.

SIL provides a variant of **signal** for sending a message **<msg>** to a private pipe **<ppipe>** owned by process **<proc>**:

signal(<proc>, <ppipe>, <msg>)

SIL also provides a variant of **wait** for removing messages from a private pipe. The command

wait(x)

causes the current process (i.e. the one calling wait) to suspend itself if the pipe **x** is empty. When a message arrives in **x** the process will resume. If **x** is not empty, then the first value in **x** is assigned to the parameter **x** and can be referenced that way until the next time **wait(x)** is executed.

Just as with public pipes, **wait** will return the first value stored in a pipe or suspend itself if the pipe is empty.

Example 10.7

```
process whoop(x: integer);
    begin
    wait(x);
    writeln(x)
    end;

process dedoo(y: integer);
    begin
    signal(whoop, x, 10)
    end;

SIL> run(whoop, dedoo);
10
```

tclosures

A **tclosure** is to a task what a closure is to a function: a passable data item whose value is a task rather than a function.

Example 10.8

```
task delay_and_print(x:integer);
      begin
      delay(x);
      writeln('delayed for ',x,' at ',clock)
      end;

delayc == mk_closure("delay_and_print,task(lispob,integer));

task five_times(x:tclosure(lispob,integer);n:integer);
      begin
      for i := 1 to 5 do x(n);
      end;

clock := 0;
five_times(delayc,4);
```

This yields the output

```
delayed for 4 at 4.000000
delayed for 4 at 8.000000
delayed for 4 at 12.000000
delayed for 4 at 16.000000
delayed for 4 at 20.000000
```

Notice that the type of a task with no return value is **task(lispob,integer)**, and that the type of **delayc** is **tclosure(lispob,integer)**.

Chapter 11

Working with SIL Code

This chapter explains how to load, compile, and debug code and how your SIL code is protected.

Protection

In order to keep users from overwriting system code, each SIL entity (global, function, task, etc.) is assigned an integer protection level. The global

current_authorization

controls the protections assigned to SIL entities. Any attempt to redefine an entity with protection level greater than that defined by **current_authorization** will result in an error. Resetting the value of an existing global with the symbol

:=

does not require any authorization; however, resetting this type and value with this symbol

==

does require adequate authorization. System functions generally use a 0 as their protection level. The default value of **current_authorization** is -1. You can set authorizations to the level you wish by using

current_authorization := <level>

Code Organization

The SilTools environment provides facilities for compiling and linking in SIL code. These facilities make use of a well-defined directory structure for storing the various files relevant to the system. The procedures used to compile are more complex than those used to load interpreted code, partly because the underlying structure has been set up to support the maintenance of multiple versions of compiled code. You should understand this structure before compiling your code.

All files having to do with SilTools reside under a master directory called **`cim`**. The collection of all SilTools files and directories (that is, all the files and directories under **`cim`**) is referred to as the **cim tree**. The cim tree may be located anywhere in a UNIX file system. All SilTools users should have a **$CIM** environment variable whose value is the pathname of the cim tree. It is also helpful to have a link from the home directory to the cim tree called **`~/cim`**. The following information assumes that **`~/cim`** points at the cim tree.

Code in SilTools is divided into modules. A **module** is simply a grouping of related code. The source code for SilTools itself is spread throughout approximately 100 modules—one for 2D geometry, one for 3D geometry, one for menu handling, etc. Each module may have an unlimited number of versions. The SilTools tree structure is set up so that different versions of the same modules share files.

Each module and each of its versions has a name. There are no hard and fast rules for naming the module and its versions, but the usual convention is

<module name>

with a version being named

<module name><version#>

For instance, the fifteenth version of the module **`geom`** is called **`geom15`**.

The Cim Tree Structure

The following sections describe the major subdirectories of **cim**:

~/cim/templates

This directory contains all the SilTools' products. A product contains an executable version of a CimStation state.

Usually, a product is started by using the Product Administration panel, which is displayed by entering **sspa** in a shell window.

To start the product **<product>**, you can also use the following commands:

SIL> **cd ~/cim/templates/<product>**

SIL> **start**

Each product contains a **umodules** file. The **umodules** file specifies which modules are included in the product and which versions of those modules should be used.

Each line of the **umodules** file contains a module name followed by a version name.

For example, the **umodules** file of a product might consist of the two lines:

```
conveyor conveyor2
press press3
```

This signifies that version 3 of the press code is to be included in this product.

~/cim/sil/<modules>

All SIL code resides in this directory. The notation **<modules>** indicates that there is one subdirectory of **~/cim/sil** for each code module.

~/cim/mccode/<modules>

All C code resides in this directory, including both C code generated from SIL and C code written "by hand."

~/cim/mhfiles/<modules>

The header (**.h**) files for C code generated from SIL are stored in this directory.

~/cim/actions/<modules>

This directory contains auxiliary information needed for SIL code. It is generated automatically by the translator, and need not concern the user.

~/cim/builds/<versions>

There is one subdirectory of **~/cim/builds** for each version of a module. Each version directory under **~/cim/builds** has the following files:

sil_files	A file listing the names of SIL files in the module.
c_files	A file listing the names of hand-written C code.
s	A link to **~/cim/sil/<my module>**
mc	A link to **~/cim/mccode/<my module>**
mh	A link to **~/cim/mhfiles/<my module>**
a	A link to **~/cim/actions/<my module>**

For example, the following directories might exist in the press **module**:

```
~/cim/sil/press
~/cim/mccode/press
~/cim/mhfiles/press
~/cim/actions/press
```

along with three versions:

```
~/cim/builds/press1
~/cim/builds/press2
~/cim/builds/press3
```

A few other directories may be present in any **cim** tree, but they are immaterial to the users of this manual.

Loading SIL Code

SIL files should be named with a **`.sil`** extension. To load a file containing SIL code, use this syntax:

SIL> **sil_load(<pathname>);**

For instance,

SIL> **sil_load('~/mysil/application1.sil');**

A shorter form is

SIL> **ld(<pathname-without-extension>);**

For example,

SIL> **ld('~/mysil/application1');**

sil_load commands may appear inside of files loaded using **sil_load**. This allows you to set up initialization sequences of arbitrary complexity—a master initialization file might load a series of files which in turn load other files, and so forth.

Creating a New Product

The following is a step-by-step description on how to create a new product.

1. Enter this command in a shell window:

   newproduct <product>

   This script will create the following:

   directory **`~/cim/templates/<product>`** file
   `~/cim/templates/<product>/top_init.sil` file
   `~/cim/templates/<product>/base*` file
   `~/cim/templates/<product>/umodules` directory
   `~/cim/gui/help/<product>`

top_init.sil contains special initializing information for a product, **base*** are the layout configurations for the product. **umodules**, initially empty, lists the modules comprising the product. **~/cim/gui/help/<product>** is a directory to hold online help files.

2. Create at least one new module, so there is a place to put code specific for this product. To do this, enter:

   newmodule <module> <first version>

   newmodule creates directories for the module as well as the first build area to include in the new product.

3. Add the following line to the file **~/cim/templates/<product>/umodules**:

   <module> <first version>

4. Copy the top bar panel from **~/cim/gui/panels/mgui** into the new module's panel area by entering

   cp ~/cim/gui/panels/mgui/top_bar ~/cim/gui/panels/<module>/top_bar

   The top bar panel may then be customized using the *Visual SIL Window* for the new product.

5. Add the top bar to the new build area by editing the file **~/cim/builds/<first version>/panels** and adding the line

   top_bar

   When the product is built, the new top bar will be included.

6. Edit the product's **top_init.sil**, replacing the line

   top_bar := ibase$top with top_bar := <module>$top_bar

   When the product is built, the new top bar will replace the default.

7. Copy the file **~/cim/gui/help/mgui/help.sil** into the new help directory by entering

   cp ~/cim/gui/help/mgui/help.sil ~/cim/gui/help/<product>

8. Edit the file **~/cim/gui/help/<product>/help.sil** to add online help for panels new to the product. Online help is optional. The help files should be placed in the **~/cim/gui/help/<product>** directory.

9. Edit the **top_init.sil** file and add the line

   ld('~/cim/gui/help/<product>/help');

10. Once all code has been written and the SIL code has been compiled, enter

    scope_out <product>

11. For each module which contains new code, use

    remake <module> <product>

    to execute the second stage of compilation from C to binary.

To build the product, which will create the new executable and **heap_file**, call

rbuild <product> base

Do not use **sspa** to build products with SilTools, as it was not designed to work in a development environment.

Compiling SIL Code

This section contains descriptions of the procedures used to create a module of SIL and C code, to compile this code, and to create a product which includes the code. Suppose that the module in question is to be called **ted**. If no version of **ted** exists, the following command creates a completely new module, with one version: **ted1**.

>newmodule ted ted1

The **newmodule** command automatically sets up all the directories listed at the top of the page:

```
~/cim/mccode/ted
~/cim/sil/ted
~/cim/mhfiles/ted
~/cim/actions/ted
```

and

```
~/cim/builds/ted1
```

The **newmodule** command also sets up the **s**, **mc**, **mh** links in the **~/cim/builds/ted1** directory.

Example 11.1

Suppose that two SIL code files have been written (**file1.sil** and **file2.sil**) and two C code files (**cfile1.c** and **cfile2.c**) for **ted**'s application. The former files should be placed in the **~/cim/sil/ted** directory, and the latter in the **~/cim/mccode/ted** directory.

To indicate that these are the files that make up the module **ted**, we create the files **sil_files** and **c_files** in **~/cim/builds/ted1**, with the following contents:

```
sil_files:
    file1
    file2

c_files:
    cfile1
    cfile2
```

Example 11.1 shows how each of **sil_files** and **c_files** is a two-line text file giving the names of the files to be included—without their **.sil** or **.c** extensions.

Compiling the code is a two-step process. First, the SIL code is translated to C, and then compiled to binary. The first step is accomplished with a SIL command, and the second step with a shell-window command.

The SIL command

SIL> **compile_area(<module>,<version>);**

compiles all of the SIL files in the given version of the given module. For example:

SIL> **compile_area('ted','ted1');**

compiles the SIL files for **ted**. To compile an individual SIL file, use

SIL> **compile(<module>,<version>,<file>);**

For example:

SIL> **compile('ted','ted1','file1');**

If we are executing these commands in a product which already includes version **ted1** of the module **ted**, the version information is not necessary. In this case, the commands are

SIL> **compile_area(<module>);**

and

SIL> **compile(<module>,<file>);**

For example:

SIL> **compile_area('ted');**

SIL> **compile('ted','file1');**

Once the SIL files are compiled, the second stage of compilation (from C to binary) is accomplished via the following shell command:

>remake <module> <product>

This remakes the given module for inclusion in the given product. The version used is determined from the versions file in the product.

NOTE The first module must be included in the product's **umodules** file and the **scope_out** script must be run.

For example:

>remake ted tedsproduct

In this example, the **remake** command also compiles any code included in **c_files**. In our example, these files are called **cfile1** and **cfile2**. Whenever SIL code is re-compiled from SIL to C, the next remake done on the module re-compiles the newly-generated C code. However, editing a hand-written C code file will not, by itself, force **remake** to re-compile that file.

To re-compile a file, add the name of the modified C file to the end of **~/cim/builds/<version>/new_c_code**. The next time the module is remade, the code file in question will be re-compiled.

Finally, to rebuild a product, use

>rbuild <product>

For example:

>rbuild tedsproduct

Again, to create a completely new product, use

newproduct <product>

After these products and files have been created, and the relevant compiles and remakes have been done, the **rbuild** command will complete the process. After **rbuild** is finished, the **start** command starts up the product. The **rbuild** command may be used repeatedly on the same product as modifications are made and compiled into that product.

Creating New Versions

This section describes the process of adding new versions of a module to the original module. For example, suppose we wish to add enhancements to the **ted** module without disturbing the working version **ted1**. A new version of module **ted** may be created using

>newversion ted ted2

This command will set up the directory **~/cim/builds/ted2**, with contents that are initially identical to those of **ted1**. Suppose next that we create a new version of our **file1.sil** SIL file, and call it **file1_2.sil**. This new version should be placed in **~/cim/sil/ted** (the same directory in which **file1.sil** resides). To compile it, use:

```
SIL> compile('ted','ted2','file1_2');
```

To include **file1_2.sil** in **ted2**, you can simply edit **~/cim/builds/ted2/sil_files** to mention **file1_2** instead of **file1**. To include **ted2** instead of **ted1** in **tedsproduct**, we edit its version file **~/cim/templates/tedsproduct/versions**. The following command:

```
>remake ted tedsproduct
```

will remake **ted2**, and

```
>rbuild tedsproduct
```

will rebuild the product with **ted2**.

Including Modules and Products in the Product Administration Panel

The Product Administration panel is used to create and start new products. The panel is displayed by entering **sspa** in a shell window.

Adding New Modules

All the available modules should be listed in the Available Modules list in the Create Product panel (which is displayed by selecting *Create...* from the **Products** pulldown menu in the Product Administration panel). Modules may be made available for use in the Product Administration panel by editing the file **cim/options/versions** and adding the line:

```
<module> <version>
```

A module should be listed only once.

Adding New Products

All the available products should be listed in the Select Product to Start list in the Product Administration panel. Products may be made available to be built in the Product Administration panel by creating an application solution module (**appsol**), which should contain the following files:

1. **`supmodules`** (lists the modules to be included in the product).
2. **`top_init.sil`**.
3. **`welcome.msg`**.
4. **`startup.msg`**.
5. layout files.
6. **`appsol`** (marking the module as an **appsol**).

The **appsol** can then be used in the Product Administration panel by first editing the file **`cim/options/versions`** and adding the line

```
<module> <version>
```

Again a module should be listed only once.

Dependency Management

SilTools has a mechanism for handling dependencies between modules (build areas) which ensures that dependent and supporting modules are included during product creation.

Modules

Two files can be created and placed in the **`cim/build/<mybuild>`** directory to supply information about any dependencies in the **`mybuild`** build area. These two files are

`supmodules` This file specifies the build areas that must come *before* the **`mybuild`** build area when creating a product.

comodules This file specifies the build areas that must also be included when the **mybuild** build area is included in a product (when the order is unimportant).

Both **supmodules** and **comodules** have the same syntax. Modules listed in the **supmodules** file (within the **cim/build/<mybuild>** directory) will be linked in *before* the **mybuild** build area during product creation. A simple example of a **supmodules** or **comodules** file is

```
robot
paint paint14
arc
```

In this example, no version is specified for **robot**. Therefore, the current version for **robot** will be used (listed in **cim/silspec/versions**). For **paint**, **paint14** is indicated. Since no version is specified for **arc**, the current version is used (listed in **cim/options/versions**).

umodules

umodules is a file which can be used to specify all modules to be included in a product. The **umodules** file (which resides in **cim/templates/<mytemplate>** area) has syntax like the **supmodules** and **comodules** files.

For example, to create a product with **appsup11**, the current version of **rkintf**, **arcweld7**, and the current version of **paint**, the **umodules** file would read

```
appsup appsup11
rkintf
arcweld arcweld7
paint
```

To set up your product with a **umodules** file:

1. Create a directory for your product (**cim/template/<mytemplate>**).
2. Create the **umodules** file.

3. Use the **ncreate_template** script (by entering **ncreate_template template_name**) to create your product.

While creating a product, **ncreate_template** calls the **scope_out** script. The **scope_out** script reads the **umodules** file, does the dependency checking and writes the traditional modules and versions files to your product area.

Using the **umodules** file is helpful when you want to remake an existing product and want to change the version of one of the modules you include, or make an addition or deletion.

"if" Syntax

supmodules, **comodules** and **umodules** files can also use **if** syntax. An example of this syntax is

```
robot robot13
paint
spot spot14
if arc
mybuild mybuild12
appsup
fi
```

In this example, **robot** version 13 is specified, the current version of **paint** is specified, and **spot** version 14 is specified. Then, the **if** block indicates that if (any version of) **arc** is included in the build, then **mybuild** version 12 and the current version of **appsup** should also be included.

"Support Only" Builds Areas

A builds area which is used only as a supporting module for some other builds area(s) can be marked so that it is not offered to the user as an option when using the Product Administration panel (**sspa** script) to create a product. To mark a builds area as "support only," create an empty directory in the supporting module build area with the name: **support_only**.

Application Solutions Header Module

If your project involves a number of builds areas, you can create an application solutions header module.

To do this, make an entry in the **cim/options/versions** file and create a directory in the **cim/builds** directory (such as **MYPROJECT1.0**). Within that directory, create an empty file called **appsol**, and a **comodules** and/or **supmodules** file.

When you use the Product Administration panel to create a product, and you select your application solution (**MYPROJECT1.0**), all of the **comodules** and **supmodules** files from the builds areas which comprise the application solution will be read.

Based on the information that is read, the Product Administration panel will create a new modules file and write it to your product area. All the components of the application solution will be included in this newly created modules file. Various initialization files and **start_up.msg** will also be copied from the application solution (**MYPROJECT1.0**) to your product area.

Patching in Interpreted Code

SIL allows interpreted versions of functions to overwrite their compiled versions. For instance, suppose that a function, **teds_function**, has been compiled into a product. If we wish to test a modification to this function, we can load or paste in a new version of code for the function, and the new code will take effect immediately. That is, whenever **teds_function** is called by any other function in the system (whether compiled or interpreted), it is the most recently-loaded version that is called—*not* the original compiled version. The process of overwriting compiled with interpreted code for a function is called **patching** the function. The ability to patch code is very useful, since it allows code to be enhanced, tested, and debugged without going through a compile and link cycle.

Debugging

Whenever possible, debugging should be done with SilTools in Text Mode. Catching errors while still using the menus and panels is discussed at the end of this section.

REMINDER	Text Mode is obtained by selecting *Exit Menus* from the **File** pulldown menu. In Text Mode, the menus and panels are disabled and the SIL> prompt is displayed in the shell window you used to start the session.

When an error occurs while running SIL in Text Mode, an error message is printed, along with the following prompt instead of the SIL prompt:

```
Error>
```

The Error> prompt indicates that an error break has occurred. During an error break, any SIL command is legal. In addition, the call stack becomes accessible for examination. The **call stack** is a data structure which describes the function which was running when the error occurred, and the sequence of function calls which led to the function invocation. The call stack also contains the values of all local variables in the functions on the stack.

This SIL command is used to examine the stack by printing a trace back:

```
Error>  tb();
```

Example 11.2 shows a typical function, function call, error message and trace back.

Example 11.2

Consider the functions:

```
function blow_up(x:string):string;
var z:string;
begin
z := '';
for i := 1 to 10 do begin z := x * z;error('blow up error');
end;
blow_up := z;
end;;

function calls_blow_up(x:string):string;
var y:string;
begin
y := x * x
calls_blow_up := blow_up(y * '_blow_up');
end;;
```

Then

```
SIL> calls_blow_up('bang');
error: blow up error
("SIL break")
"in nSIL_error"
"r(); to return"
Error>
```

continued on next page

Example 11.2 (continued)

Using the command **tb();** gives these results:

```
Error>    tb();
0  I_TEVAL(LISPOB)
1  I_TEVAL1(LISPOB)
2  PM_EXECUTE(IFORM)
3  CALLS_BLOW_UP environment:
   ARG X = bang
        Y = bangbang
        G3_CALLS_BLOW_UP = <NULL S_T_R>
4  BLOW_UP environment:
   ARG X = bangbang_blow_up
        Z = bangbang_blow_up
        I = 1
        _S_33 = 1
        _S_34 = 10
        G2_BLOW_UP = <NULL S_T_R>
5  POST_ERROR_FUN()
```

The numbers in the **0** column are the indices of the stack frames, and are called **frame numbers**. These numbers are used to refer to frames in commands described in the succeeding pages. The values of all local variables, including parameters, are printed (parameters, however, are labeled **ARG**).

In Example 11.2, the frames numbered **0**, **1**, **2**, and **5** designate system functions, while **3** and **4** are the frames of the user functions **CALLS_BLOW_UP** and **BLOW_UP**.

The **tb** command works for both interpreted and compiled code. When it is used with compiled code, however, only function names (and not local values) are available. To see the values of local values in the compiled code for a function, we can patch in its source code, and the local values for that function will be available to **tb** and other stack examination facilities. This means we do not need to regenerate the error using interpreted code to see local values—patching the function into the existing error break is adequate.

If **tb** is given an integer argument, only the specified number of frames above the debug frame will be printed. For example, the following **tb** command, with its argument, would only print frames **4** and **5** from Example 11.2:

```
Error>  tb(2);
```

The command:

```
Error>  tbn();
```

is identical to **tb**, except that it prints no local or parameter values. The example below illustrates the use of the **tbn** command:

Example 11.3

```
Error>  tbn();
0  I_TEVAL(LISPOB)
1  I_TEVAL1(LISPOB)
2  PM_EXECUTE(IFORM)
3  CALLS_BLOW_UP(S_T_R)
4  BLOW_UP(S_T_R)
5  POST_ERROR_FUN()
ok
```

The following command returns the value of the given variable in the given frame as a universal:

```
Error>  ev(<variable name>,<frame number>);
```

For example:

Example 11.4

```
Error>  ev(y,3);
[UNIVERSAL: bangbang OF_TYPE STRING]
```

The **debug_frame** variable is initially set to the frame number of the function in which the error occurred. The following commands are equivalent:

```
Error>  ev(<variable name>);
Error>  ev(<variable name>,debug_frame);
```

You are free to reset **debug_frame**, thus changing the behavior of the single argument variant of **ev**.

In our example, the error was caused by an explicit SIL error statement. Other errors arise from the usual UNIX error conditions: access violations, arithmetic errors, interrupt signals, etc. Regardless of the source of the error, the behavior of the error break is the same.

The command

Error> **r();**

returns control to the top level SIL loop; that is, it exits the error break and cleans up the stack. Continuing from the error along the same course of computation that caused the error is not possible. However, you can include statements in your code which will cause a **pause break** (a break with behavior identical to an error break but one from which computation can be continued using the **go** command. This command is

ppause(x:string);

Using the command and argument above results in x being printed out when the pause break is entered. Example 11.5 provides an extended example of **ppause**.

Example 11.5

```
procedure test_pause(n:integer);
    begin
    for i := 1 to n do ppause('testing');
    end;

SIL> test_pause(20);
pausing at testing
go; to continue
```

continued on next page

Example 11.5 (continued)

```
Pause>  tb();
0  I_TEVAL(LISPOB)
1  I_TEVAL1(LISPOB)
2  PM_EXECUTE(IFORM)
3  TEST_PAUSE environment:
   ARG N = 2
         I = 1
         _S_39 = 1
         _S_40 = 2
4  PPAUSE(S_T_R)
ok

Pause>  Pause> go;
pausing at testing
go; to continue
Pause> tbn();
0  I_TEVAL(LISPOB)
1  I_TEVAL1(LISPOB)
2  PM_EXECUTE(IFORM)
3  TEST_PAUSE(INTEGER)
4  PPAUSE(S_T_R)
ok

Pause>  ev(i,3);
[UNIVERSAL: 2 OF_TYPE INTEGER]

Pause>  go;
ok

Pause>  r();
Restarting…
Unwinding stacks…
Debug version of SIL

SIL>
```

Debugging in Menu Mode

This section discusses debugging code which causes errors while you are still using the menus and panels. The SIL flag

to_text_mode_on_error

controls what happens when an error condition is encountered in Menu Mode. When the flag is set to **true**, any error encountered by the system will cause SilTools to switch to Text Mode automatically, and display the ERROR> prompt. This flag is useful when tracking bugs. The default setting of the flag is **false**. When it is set to **false**, errors are reported, but panels stay up and no error prompt results.

Calling C Code from SIL

This section describes how C code can be called from SIL. Topics in this section are

- *Sample .c and .h Files*
- *Passing Data Types to C*

REMINDER	The procedure for including hand-written C code in a module was discussed in “Loading SIL Code” on page 11-5.

The following command imports the given C function and assigns it the given SIL type:

c_import("<function name>,<type>);

For example:

c_import("foo,map(integer,integer));

will import a C function **foo** on integers. After that process is complete, **foo** can be treated just like any other SIL function on integers—it can be called freely from SIL code, as in

```
SIL> for i := 1 to 10 do writein('foo of '<i,' = ',foo(i));
```

The only restriction is that the SIL file in which the **c_import** occurs must be compiled—not interpreted. Furthermore, patching over a compiled **c_import** will prevent it from functioning thereafter.

Importing a C function into SIL is quite simple. For integers and reals, only a **c_import** command is needed. One restriction exists: all C functions imported into SIL must obey the "reals last" rule which requires real parameters to appear after parameters of other types in the parameter list. **lrecord**s or arrays can be used to pass structured data back and forth to C. C code may read values from these **lrecord**s and arrays, and stuff new values into them as a way of returning structured data. Alternatively, the types described in "C Data Types" on page 9-15 may be used to create data structures in SIL which are identical to C data structures, and can be freely shared between SIL and C code. The only style of sharing which will not work is to attempt to build SIL data structures like lrecords and SIL arrays in C code. This is because all structured data in SIL needs to be allocated in a way that is consistent with garbage collection methods in SIL, so simple C mallocs will not do.

NOTE SIL integers correspond to the C type **int**, and SIL reals correspond to the C type **double**).

Interfacing to Existing C Code

Of course, in many applications, the task will be to interface to an existing body of C code, rather than to write new C code for use with SIL. In the former case, unless it is very simple, wrappers written in C will be needed for transporting data between SIL and the application.

Sample .c and .h Files

The remaining issue is what C declarations should be given to inputs from SIL. SIL provides a facility for automatically generating such declarations. Namely, whenever a SIL file which contains **c_imports** is compiled, sample **.c** and **.h** files are generated. These sample **.c** and **.h** files contain these declarations, and samples of their use. The sample files are placed in

~/cim/mccode/<filename>_sample.c

and

`~/cim/mhfiles/<filename>_sample.h`

These sample files are meant to be copied to your own files (with different names so that they will not be overwritten), where the function bodies will be filled in.

IMPORTANT	The **include** line in the **`.c`** file which mentions the sample **`.h`** file should be changed.

Alternatively, the sample files may be used solely as documentation. The types which will appear in the sample **`.h`** file will include all those referenced in the **c_import** commands—not just those that happen to be defined in the file containing the **c_import** commands.

Example 11.6

Suppose that the following types have been defined:

```
type lpoint = lrecord
    xc,yc,zc:real;
    end;

type point = record
    xc,yc,zc:real;
    end;;
```

Suppose further that the file **`~/cim/sil/ted.sil`** has the contents

```
c_import("cfun1,map(integer,point,real));
c_import("cfun2,map(lpoint,lpoint,real));
c_import("cfun3,map(integer,darray of real, list of ob,
darray of lpoint,
darray of point));
```

The following sample files would be generated:

Example 11.6 (continued)

```
~/cim/mhfiles/ted/ted_sample.h:
/* SAMPLE .h FILE */
        struct point {
        integer typenum_field;
        real xc;
        real yc;
        real zc;
        };
        typedef struct point *pointp;
        struct lpoint {
        integer typenum_field;
        real xc;
        real yc;
        real zc;
        };
        typedef struct lpoint *lpointp;
        typedef real *real_array;
        typedef lpointp *lpointp_array;
        typedef struct point *point_array;

============= END OF FILE ====================
```

continued on next page

Example 11.6 (continued)

```
~/cim/mccode/ted/ted_sample.h:
/* SAMPLE .c FILE */
        #include "compiled.h"
        #include "precomp.h"
        #include "e2c.h"
        #include "ted_sample.h"
        #include "postcomp.h"

        integer cfun1(a0,a1)
        point a0;
        real a1;
        {
        /* FUNCTION BODY */
        }


        lpointp cfun2(a0,a1)
        lpointp a0;
        real a1;
        {
        /* FUNCTION BODY */
        }


        integer cfun3(a0,a1,a2,a3)
        real_array a0;
        lispob a1;
        lpointp_array a2;
        point_array a3;
        {
        /* FUNCTION BODY */
        }

 ============ END OF FILE ====================
```

Passing Data Types to C

Passing Records to C

Records, as well as **lrecord**s, can be passed to C. Records are passed by reference, even though they are passed to SIL functions by value. No problems will arise from passing records to C, but attempting to return values in records, rather than **lrecord**s, is discouraged.

A SIL **lrecord** or record type **<type>** generates a corresponding **struct** declaration of the same name, and defines **<type>p** to be the type of pointer to this type. **<type>p** is the type assigned to incoming arguments from SIL. Since passing of records and **lrecord**s to C is identical, the type **lpoint** and **point** generate C declarations of identical structure. Notice, however, that an array of points and an array of **lpoint**s differ—the former is given by a pointer to a point and the latter by a pointer to a pointer to an **lpoint**.

Passing Other SIL Types

The SIL type **string** is passed to C as **stringob** (discussed further in the “Protecting the Data Space when Passing Strings” on page 11-32). The rest of the SIL types (excluding the ones already mentioned) are passed simply as **lispob**. The sample C file starts with a few includes. These inclusions bring in various basic definitions associated with the underlying implementation of SIL in C. It is here that the types **stringob**, **lispob**, **real** and **integer** are defined.

Passing a SIL Array

A SIL array is passed to C as a pointer to some header information used in SIL—not to the beginning of the array itself. The first element of the array is arrived at by using the macro **ARRAY_BODY**, and its length by **array_length**.

Example 11.7 provides a more complete example, in which functions for doubling an **lpoint** and for doubling an array of points are imported.

Example 11.7

First import the file (**`ted2.sil`**):

```
c_import("double_it,map(integer,lpoint));
c_import("adouble_it,map(integer,darray of point));
```

Compilation of this file yields the sample files shown below.

```
~/cim/mhfiles/ted/ted2_sample.h:
/* SAMPLE .h FILE */
        struct lpoint {
        integer typenum_field;
        real xc;
        real yc;
        real zc;
        };
        typedef struct lpoint *lpointp;
        struct lpoint {
        integer typenum_field;
        real xc;
        real yc;
        real zc;
        };
        typedef struct point *pointp;
        typedef struct point *point_array;

 ============END OF FILE====================
```

continued on next page

Example 11.7 (continued)

```
~/cim/mccode/ted/ted2_sample.h:
/* SAMPLE .c FILE */
        #include "compiled.h"
        #include "precomp.h"
        #include "e2c.h"
        #include "ted2_sample.h"
        #include "postcomp.h"

        integer double_it(a0)
        lpoint a0;
        {
        /* FUNCTION BODY */
        }


        integer adouble_it(a0)
        point_array a0;
        {
        /* FUNCTION BODY */
        }
 ============= END OF FILE====================
```

Next, the sample files are copied to files renamed cted2:

~/cim/mccode/ted/ted2_sample.c is copied to
~/cim/mccode/ted/cted2.c and

~/cim/mhfiles/ted/ted2_sample.h is copied to
~/cim/mhfiles/ted/cted2.h.

continued on next page

Example 11.7 (continued)

cted2.h does not need modification. Filling in the code for **cted2.c** yields:

```
#include "compiled.h"
#include "precomp.h"
#include "e2c.h"
#include "cted2.h"
#include "postcomp.h"

integer double_it(a0)
lpoint a0;
{
     a0 -> xc = 2 * a0 -> xc;
     a0 -> yc = 2 * a0 -> yc;
     a0 -> zc = 2 * a0 -> zc;
}

integer adouble_it(a0)
point_array a0;
{
point_array a0_goods;
integer ln,i;
in = array_length(a0);
a0_goods = (point_array)ARRAY_BODY(a0);
for (i=0;i<ln;i++)
   double_it(&(a0_goods[i]));
}
 =============END OF FILE====================
```

This is C code which actually doubles the entities in question. To install this work in the **ted2** version of the module **ted**, add the following line to **~/cim/builds/ted2/sil_files**:

ted2

and the line

cted2

to **~/cim/builds/ted2/c_files**

continued on next page

Example 11.7 (continued)

After a remake and **rbuild**, the imported C code is available:

```
SIL> double_it(mk_lpoint(1,2,3));
2184488

SIL> ll == mk_lpoint(1,2,3);
TRUE

SIL> ll
[LTUPLE: 6.000000,4.000000,6.000000]

SIL>
```

NOTE **double_it** returns a "garbage value" because the code for **double_it** did not bother to execute a return. This is harmless.

```
SIL> aa == array_create(point,4);
TRUE

SIL> for i := 0 to 4 do aa[i] := [i,i,i] as point;
ok

SIL> aa;
[ARRAY: [TUPLE:
0.000000,0.000000,0.000000],[TUPLE:
1.000000,
1.000000,1.000000],[TUPLE:
2.000000,2.000000,2.000000],[TUPLE:
3.000000,3.000000,3.000000],[TUPLE:
4.000000,4.000000,4.000000]

SIL> adouble_it(aa);
11612136

SIL> aa;
[ARRAY: [TUPLE:
0.000000,0.000000,0.000000],[TUPLE:
2.000000,
2.000000,2.000000],[TUPLE:
4.000000,4.000000,4.000000],[TUPLE:
6.000000,6.000000,6.000000],[TUPLE:
8.000000,8.000000,8.000000]
```

Protecting the Data Space when Passing Strings

As mentioned earlier, SIL strings are passed to C with the type **stringob**. SIL strings differ from C strings in that they include a header which consists of a type tag and a length, and are not necessarily null terminated—the length field in the header determines how long the string is, not the first occurrence of a **nul** in the sequence of bytes which make up the string. The C function **strlen** will return the length of a **stringob**, while **STRING_BODY** will yield a pointer to the beginning of the string itself. The functions **l2c_str** and **c2l_str** convert back and forth between the SIL and C representations of strings: **l2c_str** converts from SIL to C strings, and **c2l_str** should only be used to return a single value directly to SIL, as in

```
return c2l_str(<a C string>);
```

If **c2l_str** is not used in this fashion, the data space of SIL may be corrupted.

Appendix

Using SilTools in a Non-English Environment

Using SilTools in a Non-English Environment (SGI only)

1. Specify the desired locale in **`~/.lang`** (e.g. **`ja_JP.EUC`**). Refer to the SGI documentation for further information.
2. Log out and log in again so that the environment variable **$LANG** is set to the desired locale (e.g. **`ja-JP.EUC`**).
3. Add the following line into **`top_init.sil`** (if it does not exist):

   ```
   international_release := true;
   ```

4. For Japanese, edit the X application resource file **`Cimstation`** to change all **`fontList`** resources as follows:

   Cimstation*fontList: *-helvetica-bold-r-*--14-*;--mincho-*--14-*;*--14-*:

   Cimstation*XmText.fontList: 7x14;--mincho-*--14-*;*--14-*:

   Cimstation*XmRowColumn.XmCascadeButton*fontList: *-helvetica-bold-r-*--14-*;--mincho-*--14-*;*--14-*:

   Cimstation*XmMenuShell*XmRowColumn*fontList: *-helvetica-bold-o-*--14-*;--mincho-*--14-*;*--14-*:

   and add the following resource:

   Cimstation*XmText.columns: 10

5. Start SilTools. The user should be able to enter local language into text fields.

Localizing SilTools Panels

1. Start SilTools.
2. Generate the localization header file **`to_localize`** under the template directory and the localization data files under **`~/cim/gui/locales/to_localize`** by executing the SIL command:

   SIL> **to_localize();**

The file **to_localize** simply contains the names of data files generated. Each generated data file corresponds to a panel that needs to be localized:

3. Quit SilTools.
4. Use a text editor to localize those data files and save them under **~/cim/gui/locales/<local_laguage>** where **<local_language>** is the name of the local language, e.g. **~/cim/gui/locales/japanese**.
5. Set the environment variable **CIM_LOCALE** to the local language, e.g.

   % setenv CIM_LOCALE japanese

6. Restart SilTools to create a localized version of the **heap_file** and the localization process is done. Actually, whenever SilTools is brought up, it checks the environment variable **CIM_LOCALE** and the localization header file **to_localize** in the template area. If both exist and **to_localize** is newer than **heap_file**, localization will be done for those data files under **~/cim/gui/locales/$CIM_LOCALE,** which are listed in **to_localize**. Thus partial localization can be done by editing **to_localize** before restarting SilTools.

Localizing SilTools Panels at Build Time

The localization can also be done at build time by setting the environment variable **CIM_LOCALE** and creating the header file **to_localize** in the relative build area before rebuilding a template.

At build time, SilTools checks the environment variable **CIM_LOCALE** and the localization header file **to_localize** in the template area. If both exist, localization will be done for those data files under **~/cim/gui/locales/$CIM_LOCALE**, which are listed in **to_localize**.

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